CASE WESTERN RESERVE UNIVERSITY

SCHOOL OF DENTISTRY

GRADUATE STUDIES

We hereby approve the thesis of

Donald w. Hunt, Jr.

candidate for the degree Master of Science

in Dentistry.

Signed: _____ (Chairman)

_____

_____

_____

_____

Date: December 22, 2000

A THREE-DIMENSIONAL STUDY OF THE CRANIOFACIAL GROWTH AND DEVELOPMENT OF SIXTEEN CLASS II, DIVISION 1 BOLTON FEMALES

by

Donald W. Hunt, Jr., D.M.D.

Submitted in partial fulfillment of the requirements for the Degree of Master of Science in Dentistry

Thesis Advisor: J. Martin Palomo, D.D.S., M.S.D.

Department of Orthodontics

School of Dentistry

CASE WESTERN RESERVE UNIVERSITY

January 19, 2001

A THREE-DIMENSIONAL STUDY OF THE CRANIOFACIAL GROWTH AND DEVELOPMENT OF SIXTEEN CLASS II, DIVISION 1 BOLTON FEMALES

Abstract

By

DONALD WAYNE HUNT, Jr.

The invention of the Broadbent-Bolton cephalometer in 1925 made possible the collection of three-dimensional data from biorthogonal plain film head radiographs (cephalograms). The first purpose of this study was to use this technology to collect three-dimensional landmark coordinates from sixteen female series of lateral and frontal (posteroanterior) plain film head radiographs taken of participants in the Bolton Study. The sixteen females were chosen from the Bolton sample of individuals presenting Class II, Division 1 molar relationship. The three-dimensional data was collected with the aid of a computer program, 3dCEPH©, developed for this specific purpose.

The second objective of this study was to describe and analyze shape and size changes and differences found in Procrustes comparisons of adjacent age groups (i.e., between sets of averaged landmarks). A longitudinal measure of shape change was produced via the Procrustes algorithm. The Procrustes Distance Units (PDU) at each landmark were summed within specific groups of landmarks representing four craniofacial regions. Morphological change in each region is described separately, through time (ages six, eleven, and fifteen) and for its relative contribution to craniofacial shape change as a whole. The Class I and Class II, Division 1 Bolton samples were compared using a thirty-landmark (S/D) and a twenty-two (S) landmark group. The thirty-landmark group consisted of skeletal and dental landmarks while the twenty-two landmark group consisted of only skeletal landmarks.

The third objective was to describe the shape and size changes and differences between the untreated Class II, Division 1 Bolton females and the untreated Class I Bolton females as described by Palomo 1997.

Overall it can be seen that the craniofacial complex undergoes continuous shape change from ages 6-15 in the Class II S/D and S samples as well as in the Class I S/D

and S Standards. The Bolton Class II, Division 1 female sample exhibited a longer facial pattern compared to the Class I Bolton female sample. Comparing the Class I to Class II sample, the mandibular landmarks showed the smallest difference in shape at age six and the largest difference at age fifteen. For the Class II sample, for ages 6-11, the mandibular landmarks contributed the least as a craniofacial region to the overall shape change. The maxillary skeletal and dental landmarks are more protrusive in the Class II group at all age periods compared to the Class I sample.

The Class II, Division 1 Bolton females had the largest difference in size when comparing ages 11-15 (6.5%). However, for the Class I females, the largest size difference occurred when comparing ages 6-11 (10.5%). At age six, the Class II, Division 1 Bolton females were 9.6% larger than the six-year-old Class I Bolton females. By age eleven, the difference in size decreased with the Class II sample being only 0.03% larger than the Class I Bolton female sample. At age fifteen, the Class I and Class II, Division 1 Bolton females were the same size.

The eventual addition of the male data should allow the three-dimensional information from the Bolton Study to contribute to diagnosis, treatment planning, prosthetic design, stereotactic procedures, and procedural outcome assessments of the craniofacial patient. The results of the present study will also contribute to the development of three-dimensional standards.

DEDICATION

To my mom, Susan Anderson Hunt, thank you for all of the love and support that you have given me that has allowed me to obtain my goals and be a caring person. I could not have been blessed with a better mother than you.

To my dad, Donald Wayne Hunt, D.D.S., thank you for being such a wonderful role model and friend to me and for instilling a strong work ethic that will bring success in life. I only hope that I can obtain the level of excellence that you demonstrate in all avenues of your life.

To my wife, Mary Ann Whetsell Hunt, thank you for the love and support that you have given me during this project and my formal education.

To my sister, Smyre Anderson Hunt, and my brother, Clayton Brackett Hunt, thank you for being such great siblings who have encouraged and supported me throughout my life.

To my grandfather, William George "Bunk" Anderson, thank you for being such a tremendous role model for me. Bunk, you have always gone the "extra mile" for us and you command everyone's respect and desire to be around you. I hope that I can become the true gentleman that you are.

In memorium of my grandparents, Mr. Wayne Brackett Hunt, Eunice Allen Hunt, and Maude Kelly Smyre Anderson, thank you for the love and guidance that has helped to shape my life and provide me with such special memories of great people.

ACKNOWLEDGEMENTS

Juan Martin Palomo D.D.S., M.S.D., my thesis chairman, who spent countless hours helping me with this project and for his friendship.

Dr. Mark G. Hans, and Dr. B. Holley Broadbent, Jr., my thesis committee, for their insight, guidance, and patience that made this project and my orthodontic training possible.

Mr. Mike McGraw, curator of the Bolton-Brush Study, for his skill and help in digitization of the radiographs and friendship.

Mr. Peng Peng "Perry" Zhang for his expert computer knowledge and help with this project.

Dr. David Dean for the use of the Case Western Reserve University Morphometric laboratory and its equipment that allowed this project to be accomplished.

Ms. Dina Leinweber, for her friendship and clerical support throughout this thesis and my training.

Dr. Stan Hirsch provided valuable insight into the formatting and preparation of this thesis.

My classmates and friends, Jedidiah Gass, Jay Galati, and Sally Park for their friendship and support during our training and life in Cleveland.

My other friends in the program, Laurence Golden, Rachel Hamilton, Jerry Hawk, Alex Moullas, Yumi Abei, and Gordon Groisser for their friendship and time.

To the faculty and staff of the Department of Orthodontics at Case Western Reserve University.

TABLE OF CONTENTS

Page

ABSTRACT. ii

DEDICATION. vi

ACKNOWLEDGEMENTS. viii

LIST OF FIGURES. xiv

LIST OF TABLES. xvi

Chapter

1. INTRODUCTION. 1

2. REVIEW OF THE LITERATURE. 13

2.1 Cephalometry. 14

2.2 Three-Dimensional Cephalometry. 15

2.3 Growth and Development. 19

2.4 Classification Systems. 25

2.5 Longitudinal Growth Studies. 27

2.6 Class II Malocclusion. 30

2.7 Class II Anteroposterior. 32

2.8 Class II Vertical and Transverse. 37

2.9 Purpose. 40

3. MATERIALS AND METHODS. 42

4. RESULTS. 51

Page

4.1 Overall Change. 54

4.1.1 Class II, Division 1 age 6-11. 55

4.1.2 Size Difference of Class I age 6-11. . .57

4.1.3 Class II, Division 1 age 11-15. 57

4.1.4 Size Difference of Class I age 11-15. . 59

4.1.5 Class II, Division 1 age 6-15. 59

4.1.6 Size Difference of Class I age 6-15. . .61

4.1.7 Class II vs. Class I age 6. 61

4.1.8 Class II vs. Class I age 11. 63

4.1.9 Class II vs. Class I age 15. 65

4.2 Cranial Vault. 66

4.2.1 Class II, Division 1 age 6-11. 67

4.2.2 Class II, Division 1 age 11-15. 68

4.2.3 Class II, Division 1 age 6-15. 69

4.2.4 Class II, Division 1 age 6. 70

4.2.5 Class II, Division 1 age 11. 71

4.2.6 Class II, Division 1 age 15. 72

4.3 Midface. 73

4.3.1 Class II, Division 1 age 6-11. 73

4.3.2 Class II, Division 1 age 11-15 74

4.3.3 Class II, Division 1 age 6-15. 76

Page

4.3.4 Class II vs. Class I age 6. 77

4.3.5 Class II vs. Class I age 11. 78

4.3.6 Class II vs. Class I age 15. 79

4.4 Maxilla. 80

4.4.1 Class II, Division 1 age 6-11. 80

4.4.2 Class II, Division 1 age 11-15. 82

4.4.3 Class II, Division 1 age 6-15. 83

4.4.4 Class II vs. Class I age 6. 85

4.4.5 Class II vs. Class I age 11 86

4.4.6 Class II vs. Class I age 15 87

4.5 Mandible. 88

4.5.1 Class II, Division 1 age 6-11. 88

4.5.2 Class II, Division 1 age 11-15 90

4.5.3 Class II, Division 1 age 6-15. 91

4.5.4 Class II vs. Class I age 6. 92

4.4.5 Class II vs. Class I age 11 93

4.4.6 Class II vs. Class I age 15 94

5. DISCUSSION. 96

5.1 Results Comparison to Literature. 101

6. CONCLUSION. 106

APPENDIX. 111

Page

GLOSSARY. 133

BIBLIOGRAPHY. 140

LIST OF FIGURES

Figure		Page
1	Broadbent-Bolton Cephalometer.	7
2	Broadbent-Bolton Orientator.	7
3	Steps for Procrustes Superimposition.	45
4	Landmarks Employed.	113
5	Procrustes Fit of Landmarks Comparing Intraoperator Reliability for Class II For Time 1, Time 2, and Time 3.	114
6	Procrustes Fit of Landmarks Comparing Class II from age 6-11.	115
7	Procrustes Fit of Skeletal Landmarks Comparing Class II from age 6-11.	116
8	Procrustes Fit of Landmarks Comparing Class II from age 11-15.	117
9	Procrustes Fit of Skeletal Landmarks Comparing Class II from age 11-15.	118
10	Procrustes Fit of Landmarks Comparing Class II from age 6-15.	119
11	Procrustes Fit of Skeletal Landmarks Comparing Class II from age 6-15.	120
12	Procrustes Fit of Landmarks Comparing Class II from age 6-11.	121
13	Procrustes Fit of Skeletal Landmarks Comparing Class II from age 6-11.	122

Figure Page

14 Procrustes Fit of Landmarks Comparing Class II from age 11-15. 123

15 Procrustes Fit of Skeletal Landmarks Comparing Class II from age 11-15. 124

16 Procrustes Fit of Landmarks Comparing Class II from age 6-15. 125

17 Procrustes Fit of Skeletal Landmarks Comparing Class II from age 6-15. 126

18 Procrustes Fit of Landmarks Comparing Class II to Class I at age 6. . . .127

19 Procrustes Fit of Skeletal Landmarks Comparing Class II to Class I at age 6. . . .128

20 Procrustes Fit of Landmarks Comparing Class II to Class I at age 11 . . .129

21 Procrustes Fit of Skeletal Landmarks Comparing Class II to Class I at age 11 . . .130

22 Procrustes Fit of Landmarks Comparing Class II to Class I at age 15 . . .131

23 Procrustes Fit of Skeletal Landmarks Comparing Class II to Class I at age 15 . . .132

LIST OF TABLES

Table		Page
1	Longitudinal Growth Studies that used the Broadbent-Bolton Cephalometer.	8
2	Comparison of Contribution to Overall Shape Change Between Class I and Class II Females For 30 Landmark Data Analysis.	111
3	Comparison of Contribution to Overall Shape Change Between Class I and Class II Females For 22 Landmark Data Analysis.	111
4	Magnification That Occurred During the Procrustes Superimposition.	.112

1. INTRODUCTION

The world's largest and most renowned longitudinal study of human craniofacial growth and development is the Bolton-Brush Growth Study (BBGS), located in Case Western Reserve University in Cleveland, Ohio (Bailey 1992; Subramanyan, Dean 1996). The BBGS has provided the orthodontic practitioner with accepted standards of normality of the growing child through its longitudinal analysis of cephalometric radiography. Originally, the BBGS began as two separate studies, the "Brush Inquiry" and the "Bolton Study of the Development of the Face of the Growing Child." These studies began in the Department of Anatomy of the Western Reserve University, which later became Case Western Reserve University. Today, the BBGS is housed in the School of Dentistry at Case Western Reserve University.

The Brush Inquiry began on May 29, 1929. The original director was Dr. T. Wingate Todd, whose background was in physical anthropology. Charles Francis Brush, founder of General Electric Corporation, provided

primary funding for the Inquiry. The Brush Inquiry's main objective was to observe the growth and development of the normal child. Dr. Todd felt that the objective of the study could only be met by studying healthy, live children. Up until this point in time, Dr. Todd had only a child cadaver collection to examine. The subjects represented in the cadaver collection had congenital birth defects, growth insults, or pathosis and did not represent a normal, healthy child population (Todd 1931, Palomo 1997). The BBGS used health contests to enroll children. Upon acceptance into the Brush Inquiry, the children were examined on the average of once a year based on age. Infants (0-1 year of age) were examined every three months, young children (1-5 years old) every six months, and older children every year on or about their birthday. Dr. Todd developed a protocol that examined the participants in the following five areas:

1. Physical
    a) List of body measures (25)
    b) Radiographs of 6 skeletal areas:
        1. hand
        2. elbow
        3. shoulder
        4. hip
        5. knee
        6. foot

2. Mental
   a) Psychological tests (40 different mental, skill, aptitude and personality tests)
   b) Behavioral tests (a 588-entry questionnaire)

3. Functional Health Inquiry
   a) Family physician reports
   b) Hand-eye coordination tests
   c) Psychomotor development
   d) Food preference inquiry
   e) Strength of muscle test
   f) Foot prints in weight bearing and sitting

4. Genetic and Environmental Inquiry
   a) Personal and family education
   b) Health status
   c) Familial illnesses tendencies
   d) Occupation
   e) Recreation.

5. Dentofacial
   a) Photographs
   b) Tooth and mouth conditions
   c) Unique radiographs of jaw alignment
   d) Tooth impressions

In December of 1938, Dr. T. Wingate Todd passed away and Dr. William Walter Greulich became director of the Brush Inquiry. With the United States entrance into World War II in 1941, the Brush Inquiry suffered from reduced funding, decreased supplies of radiographic film, and decreased staffing. The decision was made to discontinue data collection and transfer Brush Inquiry records to the Bolton Study in 1942. From 1928-1942, there were approximately four thousand children enrolled

in the Brush Inquiry. Of the approximately four thousand subjects, 2,890 were also enrolled in the "Bolton Study" (Hans, Broadbent, Nelson 1994).

The "Bolton Study of the Face of the Growing Child", also known as the Bolton Study began in 1928. The principle source of funding of the study came from Frances Payne Bolton and her son, Charles Bingham Bolton. Charles actually worked as a technical assistant in the collection of radiographic data for the Bolton Study. Dr. B. Holly Broadbent, Sr. was the director of the Bolton Study. The primary objective of the study was to examine growth and development of the human craniofacial and dental complexes from infancy to adulthood. The Bolton Study participants had the same periodic examinations as the Brush Inquiry participants. However, the Bolton Study limited its data collection to:

1. Anthropometric measurements.
2. Dental impressions.
3. Lateral and frontal (anteroposterior) plain film head radiographs.
4. Hand-wrist radiographs.

The Bolton Study continued enrollment of participants until 1959. At this point, 4,309 subjects were recorded. There were close to 50,000 dental impressions and 44,000 cephalometric radiographs. With

the cessation of active enrollment of participants, the decision was made to direct studies focused toward the assessment of the collected data. Dr. B. Holly Broadbent, Sr. continued as the Bolton Study director until 1969. Upon his retirement, his son, Dr. B. Holly Broadbent, Jr., became the Bolton Study director and he continues in this position today.

Radiographic cephalometry has its beginnings with the work of Dr. B. Holly Broadbent, Sr. In 1924, Dr. Broadbent, Sr. worked as a student of Dr. T. Wingate Todd. Dr. Todd's interest in physical anthropology spurred Dr. Broadbent's interest in craniofacial growth and development. Dr. Todd had developed a craniostat, an instrument used to hold a dry skull in a fixed position for anthropometric measurement. To the craniostat, Dr. Broadbent added a metric scale, which permitted direct measurements of dentofacial structures. Dr. Broadbent referred to this as a craniometer (Bailey 1992). In 1925, Dr. Broadbent added a radiographic film holder to the craniometer and this signified the development of the roentgenographic craniometer. The roentgenographic craniometer thus allowed the standardized collection of dry skull cranial radiographs (Palomo, 1997).

The instrument fixates the head of a living subject allowing the collection of accurate, reproducible lateral and posteroanterior (frontal) radiographs. In following studies, Dr. Broadbent developed a standard protocol in which frontal and lateral cephalometric radiographs could be applied clinically (Broadbent 1931), it was called the Broadbent-Bolton Roentgenographic Cephalometer. The Broadbent-Bolton Roentgenographic Cephalometer (Figure 1) consisted of an adjustable chair with a fixed head holder that contained mechanical porionic axis rods. The patient could be adjusted mediolaterally and vertically in order to position the patient's mid-saggital plane with the fixed head holder. There are two x-ray tube heads located 90° to each other. The lateral tube head is positioned five feet from the patient's mid-saggital plane and the posterior tube head is located five feet from the mechanical porionic axis. The design of the cephalometer not only allowed a standardized way of collecting cephalograms, but also a basis for the collection of precisely co-registered biorthogonal films (Palomo 1997).

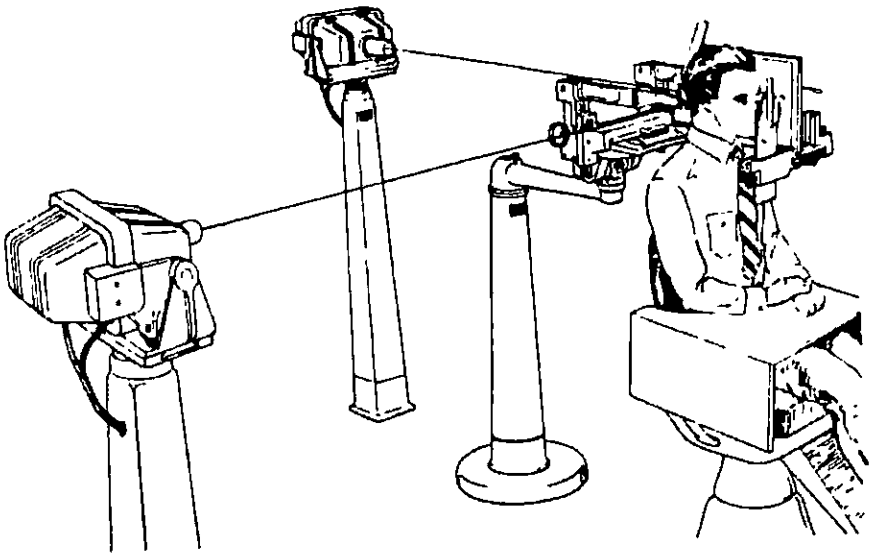


Figure 1. Broadbent-Bolton Cephalometer (© Bolton Brush Growth Study Center, presented here with permission of the BBGSC).

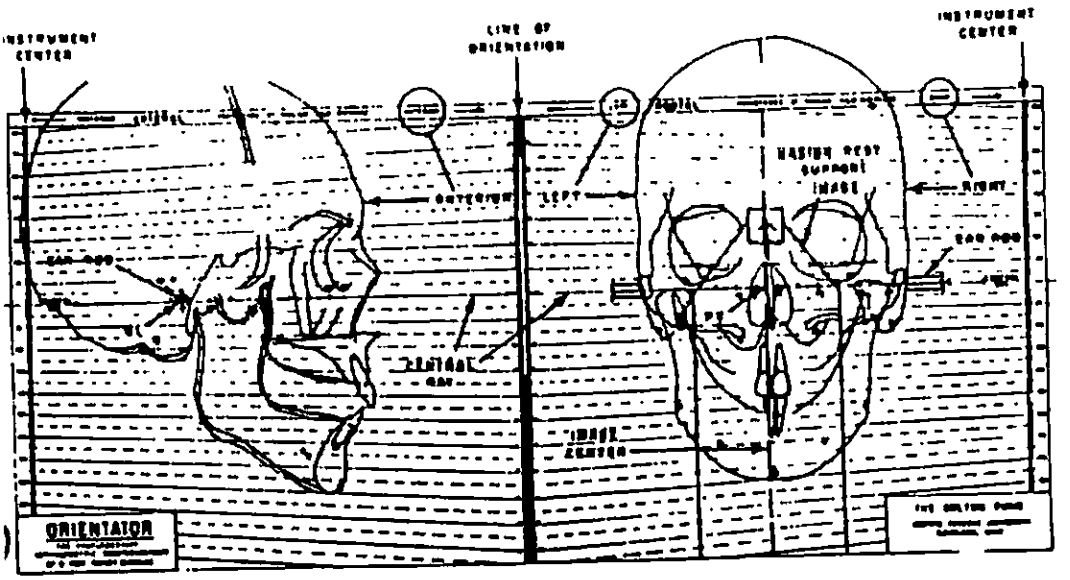


Figure 2. Broadbent-Bolton Orientator (© Bolton Brush Growth Study Center, presented here with permission of the BBGSC).

The Broadbent-Bolton roentgenographic cephalometer became the primary data collection device for several craniofacial growth studies (Table 1).

TABLE 1.-Longitudinal Growth Studies that used the Broadbent-Bolton Cephalometer

Study	Reference
The Bolton Study	(Broadbent et al. 1975)
The Burlington Growth Study	(Popovich,Thompson 1977;Saunders et al. 1980)
The Michigan Growth Study	(Primack 1978; Ackerman 1979)
The Belfast Growth Study	(Kerr 1979)
The Philadelphia Growth Study	(Krogman, Sassouni 1957)
The Denver Growth Study	(Sherman et al. 1988)
The Fels Research Institute Study	(Lewis et al. 1985)
The Forsyth Twin Study	(Medicus et al. 1971)
The Iowa Child Welfare Study	(Bishara et al. 1985)
The Matthews Implant Collection	(Baumrind et al. 1987)
The Meharry Growth Study	(Richardson 1991)
The Montreal Growth Study	(Buschang, Tanguay 1989)
The Oregon Growth Study	(Buck, Brown 1987)

Dr. Broadbent's intention was to develop a standard of normality for craniofacial development of the child from birth to age eighteen. Dr. Broadbent called these representations of normality the "Bolton Standards." From the 4,309 subjects, Dr. Broadbent selected thirty-two people (16 females, 16 males), which were called the "Bolton Faces." These thirty-two subjects were selected based on the following criteria of normality:

1. Excellence of static occlusion as viewed on the dental study casts and cephalometric radiographs.

2. A good health history, which precluded those who had significant debilitating diseases from becoming part of the group.

3. Faces that conformed in a favorable manner to the statistically derived mean of craniofacial measurements.

4. Aesthetically favorable faces as viewed arbitrarily by the Bolton Study Board of Managers.

5. Availability of long-term records, which would mean that the individual case was recorded annually from one year to eighteen years of age on a longitudinal basis (Broadbent et al. 1975).

Mr. William H. Golden was the sole technician that produced the lateral and posteroanterior radiographic tracings (Miyashita 1996). In the lateral tracings, Mr. Golden averaged all bilateral structures into a single central outline. He then divided all the tracings into age groups. The averaging process then began in which the pairs of tracings in each age group were superimposed. From these superimpositions, a third tracing was constructed using the same technique of averaging structures into a single outline. The technique was employed for each member of the age group until a single average (tracing) was produced for both

the frontal and lateral view for each group, for both sexes (Palomo 1997). Therefore, the published Bolton Standards represent two average tracings (frontal and lateral) for each age group that can be applied to both genders, because the male and female average tracings were averaged together (Broadbent et al. 1975). The published Bolton Standards for the lateral cephalogram extend from birth to age eighteen. However, the frontal Bolton Standards extend from three to eighteen years because of the difficulty of positioning an infant in the cephalometer and the long exposure time necessary to obtain the frontal radiograph during a crucial time of neural development (Broadbent 1975).

In 1975, Broadbent et al. presented the Broadbent Orientator. Based on the fact that frontal and lateral films cannot be positioned in intercepting locations, the Broadbent-Bolton cephalometer recorded the beam to cephalometer intersection point-to-film distances. By assuming the beams of the posterior and lateral tube heads orthogonally intersect in the center of the head, the correction of film distances can be calculated. The Broadbent Orientator (Figure 2) presents a two-dimensional representation of the correspondence between

points in the frontal and lateral radiographs (Palomo 1997). The diverging lines of the Orientator allow correction for the magnification as a result of the divergence of the x-ray beams from the two orthogonal single point references. The intention of the Orientator was to use the information obtained in the biorthogonal plane film radiographs and create three-dimensional data from a two-dimensional collection. However, without the use of computers, regular use of the Broadbent Orientator for three-dimensional data collection was difficult (Baumrind et al. 1983; Palomo 1997). Therefore, three-dimensional data collection was left aside until technology could catch up, allowing easier collection and interpretation of three-dimensional data.

The primary objective of this thesis is to collect three-dimensional landmarks, using a custom computer software program (3dCEPH©) based on the Broadbent Orientator, from digitized plain film biorthogonal cephalogram pairs selected from records of untreated Class II, Division 1 Bolton females. The second objective is to describe and analyze the shape and size changes found in Procrustes comparisons during growth and

development of sixteen, untreated Class II, Division 1 Bolton females at ages six, eleven, and fifteen years. The third objective is to use the Procrustes analysis to compare the shape and size changes of the Class II, Division 1 Bolton female sample to the Class I Bolton female sample established by Palomo in 1997.

2. REVIEW OF THE LITERATURE

The key to successful orthodontic therapy is accurate diagnosis and treatment planning. An orthodontist employs various sources of information to aid in the diagnosis of a case. The sources of diagnostic information include the following: patient history and questionnaire; clinical exam; intra and extra-oral photographs; panoramic radiographs; frontal and lateral cephalometric radiographs; periapical radiographs; and stone models of the patient's dentition and alveolus. Cephalometric radiography has made a major contribution to orthodontic diagnosis and treatment planning by revealing hard and soft tissue relationships transversely, vertically, and anteroposteriorly. Many cephalometric analyses have therefore been developed to establish quantitative measurements that exemplify harmony between hard and soft tissue. These cephalometric analyses have been based on longitudinal growth studies that have employed cephalometric radiography as part of its records. In fact, during the

development of modern biostatistics, human craniums were used extensively as a source of data collection. The human skull has several features that appeal to the biostatistician for research. The skulls are complex structures that vary widely in shape during ontogeny, through phylogeny, and between species. For clinical investigation, the human skull is a prime indicator of racial identity and prehistorical biological relationships. At the turn of the twentieth century, there was no way to properly measure the human cranium from the inside. Therefore, biostatisticians gave little consideration to ontogenetic biologic processes. With the introduction of cephalograms, a standardized representation of the growth of the human living skull became clinically relevant (Moyers et al. 1979). With this in mind, craniofacial biologists realized the need for longitudinal craniofacial cephalometric growth studies.

2.1 CEPHALOMETRY

Between the years of 1950 and 1985, orthodontists and craniofacial researchers primarily concentrated on the lateral cephalogram and film tracings for diagnostic information (Blafer 1971; Ricketts 1972; Hixon 1972;

Goldberg 1973; Binder 1979; Ricketts 1981; Mark et al. 1982). Beginning in the 1960's, the frontal film played a more important role in the diagnosis of asymmetries and three-dimensional studies (Baumrind, Frantz 1971; Sekiguchi, Savara 1972; Moyers et al. 1979; Vig 1982; Bookstein 1983; Adenwalla et al. 1994). Schmid et al. (1991) and Melnik (1992) noted that through ignoring frontal cephalograms, diagnosis of asymmetries was possibly overlooked, ultimately resulting in orthodontic and orthognathic treatment failures.

Savara (1965) stated the need for three-dimensional cephalometry in the diagnosis and treatment planning of orthodontic and orthognathic therapy. Since Savara's introduction, many other authors have expressed similar remarks (Solow 1970; Hixon 1972; Goldberg 1973; Maganzini 1974; Ricketts 1981; Vig 1982; Baumrind et al. 1983; Baumrind et al. 1983; Grayson 1989; Altobelli et al. 1993).

2.2 THREE-DIMENSIONAL CEPHALOMETRY

Dean and his colleagues (1997) thought three-dimensional standards could prove beneficial in studying craniofacial variations, as well as diagnosis, treatment planning, stereotactic treatment, prosthetics designs,

and outcome assessments. Altobelli called particular attention to the use of three-dimensional standards in pediatric and adult craniofacial patients (Altobelli et al. 1993; Palomo 1997).

However, the idea of three-dimensional cephalometry did not come without complications. Many different methods were introduced to abstract the data from biorthogonal head films, but these methods were not very practical. The work was hindered by hardware and software limitations, high-cost, and time consumption involved with pencil tracing of films.

Digital films, as predicted by Dr. R. M. Ricketts in 1972, would probably reintroduce three-dimensional cephalometrics (1972). Dr. Ricketts stated that the computerization of cephalometrics would yield the most powerful diagnostic tool to the practicing orthodontist. With the development of CT scans, three-dimensional images have become more realistic (Bettega et al. 1996). Bettega's (1996) opinion was that CT scans would not replace frontal and lateral radiographs in orthodontics. He attributed his doubt to the higher expense and higher radiation exposure required for CT scans compared to roentgenographic cephalograms. Tyndall et al. (1998) and

Grayson et al. (1988) published radiation doses comparing CT scans and roentgenographic cephalograms. The information stated that a pair of plain film cephalograms would introduce a twenty-six millirad skin dose to the patient. In comparison, a three-dimensional CT scan would expose the patient to approximately 6.5 rads. There is a large collection of data contained in biorthogonal plain film radiographs as a result of the numerous craniofacial growth studies. Therefore, efforts have been made to utilize computers with these databases to generate three-dimensional images. Dean and colleagues (Subramanyan, Dean 1996; Dean et al. 1997) have developed a software program, 3dCEPH©, which collects three-dimensional coordinates directly from digital cephalogram images. First, the cephalogram images must be scanned and digitized. By doing so, hand or mouse-based tracing is eliminated. The 3dCEPH© program creates a wire frame matrix between the digitized landmarks. The wire frame allows the recording of linear measurements. Dean et al. predicted that the digitized cephalograms in combination with 3D CT would become a baseline diagnostic criteria for craniofacial and

orthognathic surgical patients. In combination, the 3dCEPH© images and the images of 3D CT would provide detailed pre-surgical records for comparison with post-surgical progress (Subramanyan, Dean 1996; Dean et al. 1997).

Palomo (1997) utilized the 3dCEPH© computer program to digitize sixteen of the female Bolton Faces. Fifty cephalometric and anatomic landmarks of the frontal and lateral cephalograms were selected. Each landmark was averaged for each participant within each group. A Procrustes algorithm was employed to evaluate each landmark's relocation for the sixteen Bolton Faces being evaluated. The algorithm produced a longitudinal measure of shape change by a least square fit, which superimposes adjacent age group landmarks on a shared "centroid." Procrustes Distance Units (PDU) were calculated for individual landmark and overall Procrustes shape distances. The Procrustes algorithm as proposed by Rohlf and Bookstein (1988), provides a mechanism for optimal superimposition of two sets of homologous landmarks on their shared centroid, which is the geometric center of the object. The remaining difference between the two

sets of landmarks provides size, orientation, and positional information. The advantages of this method over traditional cephalometric superimpostiion techniques are:

1. Size is treated as a separate variable and does not over-determine the result.
2. No landmark is seen as primary or stationary during the superimposition.
3. The result is presentable in diagrammatic form that looks like the original data rather than a column of numbers (distances).

Using clinical orthodontic studies, Singh et al. (1997), recognized the Procrustes analysis as a convenient way to study geometric relationships separately from previously confounding size differences.

2.3 GROWTH AND DEVELOPMENT

Human craniofacial development, according to Moyers and Bookstein (1979), includes both pattern and growth. Pattern is described as the maintenance of the configuration of the face over time. Growth is described as the geometric changes in size and shape in craniofacial structures. In the 1950's, Melvin Moss introduced his concept of the "functional matrix." The functional matrix concept stated that the interaction

between the soft and hard tissue in the craniofacial complex determined the craniofacial morphology through function. Moss's concept was revolutionary because of its assertion that, through function, the development of the craniofacial complex could be influenced by biological and mechanical forces. Until this point in time, biologists believed that there was a set genetic predisposition in the cells of the craniofacial region. In 1964, Enlow and Harris stated that craniofacial biologists were aware of the large-scale pattern of the craniofacial growth and development. Through Enlow's research, we now know that the human maxilla grows upwards and backwards on its superior surface, as well as the condyle of the mandible. The result of this upward and backward growth, as well as surface remodeling, is a downward and forward translation of the maxillary complex and the mandible. Enlow's concept has been accepted in the biological community as the pattern of craniofacial growth and development. In orthodontics, "pattern" has a morphologic and developmental application. Orthodontists state that a patient may have a "Class II" or "Class III" facial profile pattern. However, in orthodontics and facial growth, there are semantic problems with the word

"pattern." Quantification of "pattern" may have its greatest impact in biologist's attempts to analyze craniofacial morphology. Orthodontists are interested in facial types, racial differences, sexual dimorphisms, or the understanding of an individual patient's facial skeleton prior to beginning orthodontic intervention. As orthodontists use the term, pattern means an invariance of relationships. Moyers et al. (1979) stated the following: " pattern is a set of constraints operating to preserve the integration of parts under varying conditions and through time; craniofacial pattern can be described and quantified by the identification of craniofacial constants, measures that are relatively invariant; growth is change which is best identified by analyzing those measures of size and shape that vary most sensitively over time through developmental stages; the many traditional cephalometric measures that represent well neither pattern nor growth (mixed) are of less clinical utility than either pure pattern indices or growth indices; and the analytical and conceptual separation of pattern and growth seems useful in analysis of morphology, analysis of growth, prediction of growth, and clinical treatment planning."

Numerous investigations have quantified and described bodily and facial growth changes at various periods. There is acceptance that the growth of the various parts of the head neither proceeds at the same rate nor follows the same pattern. According to Scammon (1930), the cranium follows the neural growth curve while the middle and lower anterior parts of the face follow the bodily or general growth curve. Scammon and associates described the remaining growth between the ages of ten and twenty years as 4% in the cranium and 35% in the middle and upper parts of the face. Salzmann (1974) stated that by the age of six years the growth of the brain case is almost completed, but the face is characteristically infantile. Salzmann also believed that the growth of the face was primarily influenced by environmental factors.

According to Brown (1970), the typical growth pattern of a child is characterized by a growth rate that decreases from birth, with a minor mid-growth spurt at approximately six to eight years of age, a pre-pubertal minimum, and a pubertal growth spurt. However, the timing of growth events is quite variable between individual children. A child's developmental status may

be best assessed by various physiologic parameters, rather than chronological age. These parameters may include peak growth velocity in standing height, voice changes in boys, menarche in girls, dental development, and skeletal ossification (Moore et al. 1990).

Many studies have reported on the relationship of skeletal maturity and the growth of the craniofacial complex including Thompson et al. (1973), Greulich and Pyle (1959), Tanner et al. (1975) and Liebgott (1978). Liebgott evaluated subjects of the Burlington Growth Study in Toronto, Ontario and found that peak mandibular circum-pubertal growth was closely related to Greulich and Pyle's or Tanner and Whitehouse's skeletal age than to chronological age. Pileski and Woodside (1973) used the Burlington Growth Study and reported ossification of the abductor sesamoid preceded peak mandibular growth by 1.1 year in girls and 0.7 years in boys.

Pertinent questions would be whether or not pubertal growth spurts actually occur in all children and in the craniofacial structures. Mitani (1977) found that girls and boys demonstrated growth spurts in the linear dimensions of the cranial base, maxilla, and mandible. On average, approximately 60% of his sample showed

coincidence of timing of the maximum peak occurrence. Lewis et al. (1985) similarly reported that pubertal spurts above the continuous growth occurred in the cranial base and mandible of 77% of the girls and 85% of the boys in their study. In contrast, Bishara et al. (1981) reported that pubertal spurts in the mandible were uncommon, and unpredictable, if they did occur. In 1984, Bishara et al. reported on a study that quantified the changes in facial dimensions in relationship, as well as in standing height, which occur between the age of five and twenty-five years. The sample was split into twenty males and fifteen females, and divided into three periods of growth: from 5-10 years (GP I), from 10-15 years (GP II), and from 15-25.5 years (GP III). All subjects had clinical acceptable occlusion and no previous orthodontic treatment. Bishara et al. reported that the timing and magnitude of change in the various facial parameters differ during the same growth period, as well as between males and females. Generally, most of the changes in the female parameters occurred during GP I and GP II. In males the facial changes were relatively distributed between the three periods of growth. During GP III, some parameters had a clinically significant change. In

females the ratio of anterior face heights decreased significantly. In males there was a significant increase in the measurements of Ar-Pog, SNB, and SN-Pog. In contrast, the maxillary-mandibular relationship, the ratio between anterior and posterior face heights, MP-SN angle, and the convexity of the soft-tissue profile continued to decrease significantly. During GP III, with the exception of standing height and mandibular depth, there were no significant differences in the magnitude of change between the ages of fifteen and seventeen years and the change after age seventeen. These findings suggest a mean trend, not individual, for certain facial parameters during the late growth period that may influence orthodontic and/or orthognathic treatments, both beneficially and adversely (Bishara et al. 1984).

2.4 CLASSIFICATION SYSTEMS

Orthodontists diagnose a case and must compare the case to a baseline of optimality. But, what constitutes optimality? Longitudinal growth studies contributed to the development of cephalometric analyses. As in the case of the Downs and Ricketts analyses, the subjects selected as standards were based on esthetically pleasing facial characteristics. Frontal and lateral cephalograms

were made of the selected individuals from which measurements were taken to establish clinical norms. Most of these analyses used caucasians as subjects. Dr. Edward H. Angle developed the Angle's Classification system based on a dental relationship, not skeletal. Four major groups were created: Normocclusion, Class I, Class II, and Class III malocclusions. In most cases, a patient with an Angle Class I molar and cuspid relationship have harmony between the maxilla and the mandible. Therefore, their frontal facial proportions are esthetically pleasing, and their lateral profile reveals an orthognathic relationship. Additionally, a subject with an Angle Class II molar and cuspid classification generally has a convex profile. Whether the patient is considered a Division 1 or Division 2 classification depends on the incisor relationship. An Angle Class III dental relationship typically presents with a concave facial profile. Therefore, the patient's occlusion or malocclusion may be independent of the underlying skeletal relationship or may be a direct representation of a skeletal discrepancy. Over time, the orthodontic community has generalized the evaluation of a patient's profile and lateral cephalogram by describing

the patient as having a "Class II growth pattern" or "normal Class I skeletal pattern." What the orthodontist fails to realize is that there is not a classification system developed for skeletal relationships. However, when orthodontists convey information to each other, they use these misnomers and the listener understands what the speaker is conveying. The statement, "This patient has a Class II skeletal pattern," gives the listener a probable idea of the patient's profile and dental relationship. However, this statement fails to determine whether there is maxillary hyperplasia, mandibular hypoplasia, a combination, or normal size jaws with poor relationship to each other. The specific information would be key to the treatment planning of the case. The orthodontic literature has perpetuated this misuse of skeletal nomenclature. Many studies have incorporated the system of nomenclature into their presentations.

2.5 LONGITUDINAL GROWTH STUDIES

In a study of transverse and vertical craniofacial growth by Snodell et al. (1993), longitudinal growth changes were studied from posteroanterior cephalometric radiographs of twenty-five male subjects from 4-25 years of age and twenty-five female subjects from 4-20 years of

age who had Class I skeletal and dental patterns. The results revealed that growth for males continued past age eighteen years for all skeletal measurements, except for maxillary width. Growth for females was completed by seventeen years for all skeletal measurements. The transverse measurements at age six had a greater percentage of the adult size completed than vertical measurements for both males and females. Also at age six, gender differences were in the mean width for the cranium, face and maxilla. By age twelve, the differences were in cranial width, maxillary width, and maxillary and mandibular intermolar width (6-6). At eighteen years, there were gender differences for all variables except for nasal width and mandibular intermolar width (6-6).

In a longitudinal study of growth pattern by Nanda and Ghosh (1995), the sagittal linear measurements at points A, B, and pogonion relative to the pterygoid vertical plane in a Class I sample were measured. Serial cephalometric radiographs at ages six, twelve, eighteen, and twenty-four years were traced and digitized. The sample included forty females and forty-six males. In the female Class I sample, the results indicated that

between the ages six and twenty-four years there was a total growth increment of 6.07, 7.53, and 11.17 mm at points A, B, and pogonion, respectively. In the male sample, the growth increment was 9.49, 11.65, and 16.21 mm at points A, B, and pogonion, respectively. Although the actual change in length of these measurements was larger in the male subjects than female, the growth increment in these measurements in terms of percentages from ages six to twenty-four was the same.

Palomo (1997) used three-dimensional cephalometric computer software to evaluate growth of the sixteen female Bolton Faces. A Procrustes analysis was employed to evaluate shape change separate from the change in size. Palomo's analysis separated the craniofacial complex into the following five regions: anterior vault, posterior vault, maxilla, mandible, and midface. Palomo found that the craniofacial complex undergoes continuous shape change from ages 3-18. He stated that the importance of this clinically is that what is perceived as relapse may actually be lack of expected modification. It was determined that the posterior vault region demonstrated the greatest amount of shape change. However, it was noted that some of the variation may be

due to difficulty in landmark identification. The female orbit appeared to shift superoposteriorly overall. The midface was determined to move in a superoanterior position. The dentition demonstrated protrusion and anterior movement. For an orthodontist, the growth of the maxilla and the mandible are of primary interest. Palomo deduced that intervention in the female maxillary region would have best results before age nine, if a high rate of growth was a treatment goal. For the mandible, there was five shape modification peaks observed: 3-4, 7-8, 11-12, 14-15, and 17-18 years. Palomo's results indicated that perhaps treatment limited to periods between 12-14 and 15-17 would be more productive with limited extension into adjacent ages, whereas, traditionally, orthodontics considered the entire period of adolescence to be productive. Palomo's study only investigated the female sample, and the male sample has yet to be studied.

2.6 CLASS II MALOCCLUSION

Dr. T.M. Graber (1969) stated that most orthodontic problems that are seen for correction are Class I malocclusions. However, it is generally agreed upon by orthodontists that Class II malocclusions constitute the

majority of their orthopedic corrections and the tougher orthodontic cases in their practice. According to Ast, Carlos, and Cons (1965) in a study of 1,413 high school students aged fifteen to eighteen years, they found 23.8% of people had Class II malocclusion, and 70.9% had Class I malocclusion. The ratio of 1:3 was similar to that reported by Goldstein and Stanton (1936) for Caucasian American children. Massler and Frankel (1951) reported a similar ratio for children fourteen to eighteen. In comparison, Altemus (1959) reported a Class II to Class I malocclusion ratio of 1:6 in Black American children age twelve to sixteen years (Bishara 1998). One of the main characteristics of Class II malocclusion is the excessive anteroposterior apical base difference. In "skeletal" Class II malocclusion, the orthodontic community suggests early intervention and treatment beginning in the deciduous dentition (Graber 1969, Williams 1980). A practitioner's goal is to coordinate the orthopedic correction with the patient's growth.

2.7 CLASS II ANTEROPOSTERIOR

Several authors have attempted to describe the anteroposterior cephalometric characteristics of the Class II, Division 1 malocclusion by using Angle's

classification. Fisk et al. (1953) described the following six possible morphologic variations in the dentofacial complex that would contribute to a Class II malocclusion: The maxilla and teeth are anteriorly situated in relation to the cranium; the maxillary teeth are anteriorly placed in the maxilla; the mandible is of normal size but posteriorly positioned; the mandible is underdeveloped; the mandibular teeth are posteriorly placed on an adequate base; and the final variation comprises various combinations of the aforementioned factors (Bishara 1998).

Cephalometric studies have found conflicting results as to which jaw is abnormal. In studies by Renfroe (1948), Drelich (1948), Craig (1951), Ricketts (1952), and McNamara (1981), the relationship of the maxilla to the cranial base showed no significant difference between the Class II, Division 1 and the Class I group. However, the mandible was found to be significantly retrusive. McNamara (1981) reviewed literature of sixteen previous studies. He found that twelve of the studies supported that the mandible is retrognathic in Class II, Division 1 malocclusion. The other four studies found the mandible to be normal. McNamara reported from his own studies

findings that most subjects with Class II, Division 1 malocclusion have mandibular skeletal retrusion (hypoplasia), and a smaller percentage showed maxillary protrusion (hyperplasia) (McNamara 1981). In contrast, Rothstein (1971) compared Class II, Division 1 subjects to Class I subjects, and his conclusion was the mandible was most often in normal range, but that the maxillary apical base was protrusive. Additionally, Maj, Luzi, and Lucchese (1960) found total mandibular length in 96% of Class II subjects to be similar to that of Class I subjects of the same age. Their conclusion is that the differences between the bony bases were not the result of abnormal development of any specific part, but rather, an abnormal relationship between parts.

Buschang et al. (1986) used orthogonal polynomials to study the craniofacial growth of adolescent boys from eleven to fourteen years by evaluating the variation between Normocclusion and Class II malocclusion. Between the two groups, the study found the angular relationships to the cranial base remains stable throughout the age range. Mandibular measurements showed growth velocity and acceleration indicative of the adolescent growth spurt. In comparing the boys with normocclusion with

those with Class II malocclusion, it was determined that 80% of the measurements were not significantly different. However, the mean growth velocity of Basion-Nasion was significantly greater for the Class II, Division 1 malocclusion subjects. The total mandibular length and the ANB angle display significant mean size (constant) differences between boys with normal occlusion and boys with untreated Class II malocclusion. The results found the groups were comparable in growth velocity and acceleration, therefore indicating that the size differences were established before eleven years of age and maintained during adolescence (Buschang et al. 1986).

In another study by Buschang et al. (1988), the longitudinal mandibular growth of French-Canadian children between ages six and fifteen years with normal occlusion and untreated Class II, Division 1 malocclusion was compared. This was the first published study of its type. The results found that with the exception of annual growth velocity, the curves describing the amount and direction of growth for the cephalometric landmark Gnathion were comparable for children with normal and malocclusion. It was stated that there existed a consistent tendency for boys and girls with Class II

malocclusions towards a more vertical growth direction, which would further increase anteroposterior jaw discrepancies. Clinically, there was a positive association indicating that growth directions of vertical and horizontal growers would tend to become more vertical and horizontal, respectively, with time. Therefore, subjects with Class II malocclusion and vertical growth pattern would tend to increase anteroposterior discrepancies to a greater extent than children with malocclusion alone. Horizontal growers with malocclusion were determined to present the greatest chance of successful orthodontic treatment by decreasing the need for orthopedic correction (Buschang et al. 1988).

Until 1995, few studies in the literature had presented information about craniofacial growth beyond the pubertal period. Whether or not the growth of persons with Class I malocclusion differs greatly with persons with Class II malocclusion had yet to be established. Pollard and Mamandras (1995) examined male post-pubertal facial growth in Class II malocclusion. The sample consisted of thirty-nine male subjects exhibiting Class II skeletal characteristics on a lateral cephalogram. The subjects were between sixteen and

twenty years of age and had no previous orthodontic treatment. The results showed significant increases in mean maxillary and mandibular measurements over the age period. Mean mandibular growth (Co-Gn) was approximately three times that of maxillary growth (Co-A). The total mean mandibular growth for the age period was approximately 4.3 mm. The mandible appeared to rotate anteriorly-superiorly, which was reflected by a mean reduction in mandibular plane angle of 1.47°. There was also a greater increase in posterior versus anterior face height. There were no statistically significant changes in incisor angulation. In the Class II sample, the mean growth changes were comparable to those previously recorded for male subjects with Class I malocclusion for the same age group. Thereby suggesting a similarity in post-pubertal development between a Class I and Class II malocclusion groups (Pollard and Mamandras 1995).

2.8 CLASS II VERTICAL AND TRANSVERSE

Class II malocclusions often express vertical and transverse discrepancies in addition to the anteroposterior component. Bishara et al. (1996) studied longitudinal comparisons of dental arch changes in

untreated Class I and Class II, Division 1 subjects. The researchers evaluated dental casts of fifteen males and twenty-two females of the Class II, Division 1 malocclusion group, and twenty-eight males and twenty-seven females in the Class I group. The findings indicated that the growth trends in the various dental arch parameters evaluated were similar in the Class I and Class II, Division 1 malocclusion groups in both male and female subjects. Differences between the measurements of maxillary and mandibular intermolar arch widths were greater in the Class I male subjects than in the male subjects with Class II, Division 1 malocclusions. The female subjects had similar trends, however the differences were not statistically significant. In conclusion, Bishara et al. stated that the clinician should assume that the changes in arch lengths and widths in both the subjects with Class II, Division 1 malocclusion and the Class I subjects follow the same general patterns. In contrast, it was stated that the relative constriction of the maxillary arch, as related to the mandibular arch, in Class II malocclusion is expressed from the earlier stages of dental arch development. The proposed trends continue in the mixed

and early permanent dentitions and do not self correct without treatment. Therefore, when such trends are diagnosed, early correction of the transverse discrepancy should be attempted together with that of the anteroposterior discrepancy. Similarly, Tollaro et al. (1996) reported on the role of posterior transverse interarch discrepancy (PTID) in Class II, Division 1 malocclusion during the mixed dentition phase. The study involved sixty Class II, Division 1 subjects split equally in two groups with or with out PTID. There was a control group of thirty Class I subjects in the mixed dentition employed for comparison. PTID was found to be due to a significantly narrow maxillary arch in the Class II, Division 1 group. The Class II group with PTID demonstrated mandibular retrusion associated with a posteriorly displaced mandible of normal size (functional mandibular retrusion). The Class II group without PTID demonstrated mandibular retrusion due to a micrognathic mandible (anatomic mandibular retrusion). The authors stressed the relevance of these findings for treatment planning in Class II, Division 1 malocclusion in the mixed dentition.

Additionally, in a longitudinal study by Bishara et al. (1997, 1998), the changes in dentofacial structures in untreated Class II, Division 1 subjects was compared to Class I untreated subjects. The study focused on the changes in the dentofacial structures from the deciduous to the permanent dentition. Based on a cross-sectional analysis, only mandibular length (Ar-Pog) differed significantly in the two groups, and then only during the earlier stages of development. The difference was not significant in the later stage. The authors proposed that this finding indicated that some "catch up" growth may occur in Class II individuals. The authors also stated that longitudinal comparisons of the growth trends between Class II, Division 1 and Class I subjects, indicated that there were no significant differences between the two groups, except in upper lip protrusion. Comparing the total change from the deciduous to permanent dentition revealed a few significant differences between Class II, Division 1 and Class I subjects. The differences included a larger magnitude of maxillary and mandibular lengths in the Class I group and greater skeletal and soft tissue convexities in the Class II group (Bishara 1997,1998).

2.9 PURPOSE

The practicing orthodontist is interested in the growth potential of individuals with Class II malocclusion because these individuals comprise a significant percentage of patients referred or seeking treatment. The literature reveals that a Class II malocclusion may or may not be accompanied by an underlying skeletal discrepancy. Previously, there have not been many longitudinal studies that compare untreated Class II, Division 1 subjects with untreated Class I controls. Computer technology and software design has opened the door to evaluation of three-dimensional cephalometric data. Three-dimensional cephalometry is now available for application to data collected in longitudinal growth studies. An understanding of the size and shape changes of the craniofacial structures of Class II, Division 1 subjects should prove beneficial to craniofacial biologists and practicing orthodontists.

The proposed study attempts to utilize the frontal and lateral cephalograms collected of Class II, Division 1 females of the Bolton Study and compare them to the available 3D Bolton Standards. Pairs of cephalograms for ages six, eleven, and fifteen years were selected. These

age groups correspond to the eruption of the first permanent molars, the circum-pubertal growth spurt, and the end of the adolescent growth, respectively. By digitizing the pairs of cephalograms of the untreated Class II, Division 1 Bolton females, cephalometric landmarks will be evaluated based on Palomo's (1997) study. The size and shape changes of the craniofacial structures of the untreated Class II, Division 1 Bolton females will be recorded and compared to the untreated Class I female sample of the Bolton Study.

3. MATERIALS AND METHODS

The first step in this project was to select a sample of untreated Class II, Division 1 females from the records of the Bolton-Brush Growth Study. The ages six, eleven, and fifteen years were selected to correspond with pre-, circum-, and post-pubertal growth periods. A computerized search of the Bolton-Brush Growth Study database revealed possible female subjects that were classified as untreated Class II, Division 1 malocclusion who had frontal and lateral cephalogram pairs at the selected ages. Selection of the sample was then based on examination of the plaster dental casts at age six. The Class II, Division 1 malocclusion was determined by the anteroposterior relationship of the second deciduous molars and canines. From the 147 prospective subjects, sixteen untreated Class II, Division 1 females were selected to the study sample based on model analysis and presence of frontal and lateral cephalograms at the respective ages. Additionally, hand-wrist radiographs were examined to confirm skeletal maturation based on

Greulich and Pyle's (1959) analysis. The computerized Bolton Standards for Class I females previously established by Palomo (1997) were used as the "Gold Standard" for direct comparison for shape and size changes.

In order to capture the three-dimensional landmarks from the selected sixteen female Bolton subjects, digitization of the cephalogram pairs was necessary. A Howtek "Scanmaster Dx" scanner was used to digitize each cephalogram. A PC workstation with a Pentium II™ processor, 350 MHz, and 328 RAM running Windows NT™ with a Compact Disc recorder (Plextor 8x™) was also utilized. Using a template developed in the University of California at San Francisco, four fiducial points were punched in each cephalogram to control distortion and enlargement. Once scanned, the sixteen cephalogram digitizations were saved as forty megabyte, twelve-bit TIFF images. Adobe Photoshop™ was utilized to adjust contrast, brightness, and the gray scale of each image. Upon restoration, the images were saved to a CDROM. The 3dCEPH© imaging program developed by Subramanyan and Dean (1996) was then utilized to analyze the data. The

3dCEPH© program allowed additional image correction through a twelve-bit processor and the identification via computer-mouse of fifty cephalometric landmarks in each frontal and lateral film pair. Another computer program, Procfit©, also developed by Subramanyan and Dean (1996) was used to determine the average of all the three-dimensional landmarks found for each age group. The averages were then compared to each other, using the Procrustes algorithm. For this comparison, the following two different computer programs were used; Procfit© for numerical data, and SPLUS© (Mathsoft, Inc.) for visual data in the form of Cartesian plots.

The Procrustes algorithm is a mathematical calculation that allows shape comparison of two or three-dimensional objects. The Procrustes analysis allows a best least square fit of the objects. The Procrustes Analysis is based on the following two assumptions: landmarks are homologous which means that they are created from the same biological process in two separate individuals, and that the landmarks capture the shape of the biological region of interest. The superimposition separates size from shape and compares two or more

objects with homologous landmarks. The Procrustes Algorithm has the following advantages: size is treated as a separate variable and does not overdetermine the result; no landmark is seen as primary or stationary with this superimposition technique; and the result is presentable in diagrammatic form that looks like the original data rather than a column of numbers. The Procrustes superimposition involves three steps: Translation, Rotation, and Scaling (Figure 3).

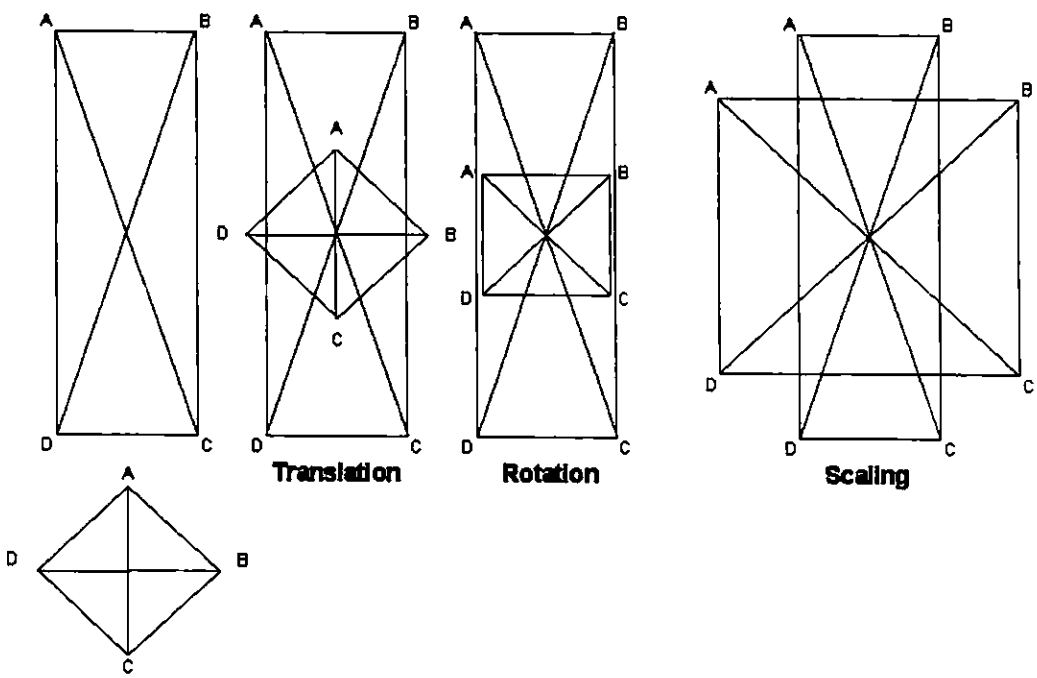


Figure 3. Steps for Procrustes Superimposition.

Translation is the centering of each set of landmarks at the origin. The origin is coincident with the "centroid." Rotation involves angular change about the centroid for all landmarks without deformation (rigid). Each set of landmarks will have minimal sum of squared deviation from the reference set. Which means that each landmark in an object will be at the closest linear distance to its homologous landmark in the other object without deformation or scaling and in the same plane. Scaling is magnification or the amount that the smaller object must be magnified in order to get the homologous landmarks closest to each other. Scaling allows the separation of shape change from size change. The centroid size is the sum of the squared distances of each landmark in the set to the centroid. After scaling, the centroid size of the two objects has the same size.

The sixteen female Bolton subjects used in this study were identified by the following Bolton Identification Numbers: B0119, B1074, B1225, B1269, B1946, B2146, B2147, B2235, B2327, B2328, B2491, B2701, B2871, B2891, B3066, and B3275. Each of these Bolton subjects contributed with posteroanterior (frontal) and lateral plain film cephalograms at ages six, eleven, and

fifteen years. A total of forty-eight pairs of cephalograms were examined.

The following lists the steps in the use of the 3dCEPH© program:

1. Align the frontal and lateral images from each visit. It is important to check if the head is facing the correct side in both images. The lateral image should be facing to the right. The frontal should display a shorter ear rod on the left.

2. 3dCEPH© presents a computer graphic version of the Broadbent-Bolton Orientator. The orientator assists the alignment of the frontal and lateral films. To align both images with landmarks identified by others, one identifies four fiducial points, which are punched holes applied prior to scanning. They form a preset rhomboid pattern. Both Porion landmarks (in this case as the center of the ear rod) are identified on both images. Nasion (see Glossary for landmark definitions) is identified on the frontal only to assist in specifying the mid-sagittal plane. When the image orientation is completed, the P+ and M1 distances are inserted. These distances determine the horizontal position of the images along the simulated x-ray beams (Fig. 3). The vertical alignment of the frontal image is accomplished by moving the image up or down so that the biporion (ear rod) axis ends up represented by a solid yellow horizontal line (the other dotted horizontal orientator lines are displayed in red). Next, in the lateral view Porion is located with the help of a size-variable circle. The center of the circle, only at this point, locates Mechanical Porion. To complete the vertical

alignment of the lateral image, Porion becomes the axis of rotation. The image is rotated until landmarks, which are identifiable in both views (i.e., Menton, Upper Incisor Edge, and Supraorbital point), are put in best alignment using the horizontal orientator lines. The final check of lateral and frontal positioning is about the Frankfort plane (Porion-Infraorbitale). Finally, Nasion is re-checked in the frontal view. It must continue to lie in the midline and be vertically coordinated with Nasion of the lateral view.

3. Once the images are aligned, the next step is landmark identification. The 3dCEPH© software displays an estimated overly of the same 50 landmarks on both the frontal and lateral views. Each landmark is manually moved to its appropriate position. Sometimes a zoomed view is necessary. Twenty-two of these landmarks can be accurately seen in only one of the image views, however the horizontal lines of the Broadbent-Bolton Orientator allow one to site the missing landmark across to the other image.

4. Following landmark identification the data is saved. Besides the x,y,z coordinate data collected, the Bolton subject's visit number, sex, date of birthday (day, month and year), date of visit (day, month and year), date of the user's digitization, name of the operator, and any possible remarks or observations are recorded (Palomo 1997).

In order to reduce inter-operator variability (Sekiguchi, Savara 1972; Moyers, Bookstein 1979; El Mangoury et al. 1987; Adenwalla et al. 1988; Major et al.

1994), Palomo and other Bolton-Brush Growth Study researchers wrote standard landmark definitions for three-dimensional biorthogonal plain film x-ray landmark identification (see Glossary). These initial definitions were based on Grayson's 3-D landmark definitions (Grayson et al. 1988). The author of the present study was calibrated by Dr. Palomo and followed the established definitions for landmark identification. In order to establish intra-operator reliability, the author identified landmarks in the three age groups in six of the sixteen subjects, thus representing 37.5% of the total sample. The author repeated the aforementioned landmark identification a total of three times within the same six subjects. The three separate collections of data were identified as Time 1 (T1), Time 2 (T2), and Time 3 (T3) respectively. The three examination time periods were then coupled thereby giving an N=54 of examined film pairs. The standard deviation was measured between the second and third data sets of measurements. The results are located in the Appendix (Figure 5).

The landmarks were collected and separated into three data sets. The first group involved the fifty landmarks as examined by Palomo 1997. The second set was

composed of thirty landmarks that Palomo et al. (1997) determined to be of the highest inter-operator reliability. The thirty landmarks were subdivided into a twenty-two skeletal landmark group and an eight dental landmark group. The third data set was composed of the twenty-two skeletal landmarks only.

The data for each age group was averaged to establish a grand mean for that age group. The resulting average was analyzed to describe the shape changes evident in the time periods from ages 6-11, 11-15, and overall change from age 6-15 years. Additionally, the averaged landmarks for the Class II, Division 1 females were compared to the "Gold Standard" of the Class I female Bolton Faces at the corresponding age. The averaged data for each landmark is in the form of Cartesian coordinates, x, y, and z. The Procrustes algorithm allowed a best-fit superimposition of the Class II, Division I females and the Class I Bolton Faces.

The last objective of this study was to analyze changes in shape and size differences between the Bolton Faces and the Class II, Division 1 Bolton female sample.

4. RESULTS

The Procrustes algorithm was used to match adjacent sets of averaged landmarks. The data was examined in three groups based on landmarks included. The first group included the fifty landmarks examined by Palomo (1997). The second group included thirty landmarks based on the thirty-two landmarks that Palomo established to be of the highest reproducibility. All figures and tables referred to in the results are located in the Appendix section. The landmarks included in the thirty-landmark analysis are listed in Figure 4. The third group consisted of the twenty-two skeletal landmarks from the group of thirty landmarks of highest reproducibility. The author of the present study found in the determination of intraoperator reliability that the overall average difference in the T1_T2_T3 fifty-landmark group to be 0.887 PDU. The fifty-landmark data was normalized and the determination of a cutoff of no more than 2.0 PDU gave the thirty landmarks that were considered to have the least amount of error in

reproducibility. The determined thirty landmarks had a lower average PDU difference (0.627 vs. 0.887) than the fifty-landmark group (Figure 5). With the intraoperator reliability being established, the decision was made to evaluate and describe the shape changes involving thirty landmarks. In Palomo's 1997 results, he reported a set of thirty-two landmarks of the examined fifty to have the highest means of reproducibility. The thirty landmarks of the present study are the same as Palomo's thirty-two landmark group with the exception of Lateral Orbitale, which is a bilateral structure. Examination of the author's data and Palomo's results revealed a discrepancy in the author's interpretation of the location of Lateral Orbitale anatomically and resulted in a large discrepancy in results. Therefore, Lateral Orbitale (Right/Left) was eliminated from this group thereby leaving thirty landmarks for direct comparison. Additionally, the present study separated the thirty landmark group further into a group of twenty-two skeletal landmarks by removing the eight dental landmarks. An effort was made to examine the skeletal shape change without influence from the dental landmarks with the Procrustes superimposition.

The dental landmarks could possibly drive the data with change during eruption of the permanent dentition. The four craniofacial regions were examined for shape change amount and direction independent of the dental landmarks.

The results of the thirty (skeletal and dental) and the twenty-two (skeletal) landmark groups are here presented by age periods. The time periods are ages 6-11, 11-15, and 6-15 years. The shape change for the untreated Class II, Division 1 and the Class I Bolton female samples are presented. Additionally, the comparison of the Class II, Division 1 Bolton female sample to the Class I Bolton female sample is presented for ages six, eleven, and fifteen.

The data for the present study was analyzed with two different methods. The first method was to employ Procrustes Distance Units (PDU) in order to quantify the amount of shape change that occurred between each age group pair. The second method involved the normalizing of the data related to the overall change contribution by each landmark. In order to simplify the analysis, the landmarks were separated into the following four craniofacial regions: Cranial Vault, Maxilla, Midface,

and Mandible. By no means is it assumed that the landmarks used fully represent a craniofacial region. The analysis was performed individually for each landmark and in no occasion were they treated as a group that defines the total shape or size of a craniofacial region. The following discussion presents the results of the thirty (skeletal and dental, S/D) and the twenty-two (skeletal only, S) landmark groups.

4.1 OVERALL CHANGE

The sum Procrustes distance for the thirty (S/D) and twenty-two (S) landmark groups are presented here. The landmarks and their subsequent positional change between age groups represent the total amount of shape change within the cranium, the mandible, and the teeth. Note that all directions of change are listed for the thirty-landmark groups. Unless otherwise noted, the directions of shape change are the same for the landmarks in both groups. As a landmark is listed, it will be followed by the amount of Procrustes Distance Unit (PDU) change exhibited for that age period and the percentage that the amount of change represents in the total or overall shape change for the age period. The size difference between

the age periods observed within Class II, Division 1 and Class I as well as between Class I and Class II, Division 1 Bolton females is also presented.

4.1.1 CLASS II, DIVISION 1 AGE 6-11

The Class II, Division 1 Bolton females exhibit the greatest amount of overall shape change in the thirty skeletal and dental (S/D) and the twenty-two skeletal (S) landmark groups within the 6-11 year old age group. The total shape change is measured as 69.29 PDU (Procrustes Distance Units) for the S/D group (Figure 6) and 31.64 PDU in the S group (Figure 7). Within the 6-11 period, Gonion Right exhibited the least amount of shape change with 0.254 PDU (0.36%) in the S/D group and 0.501 PDU (1.58%) in the S group. Gonion Right moved posteroinferiorly and laterally. In the S/D group, the Central Incisor Root Apex Left exhibited the most change with 8.172 PDU (11.8%) in an anteroinferior and medial movement. In the S group, Orbitale Left had the most change with 2.711 PDU (8.5%) superior, posterior, and medial. The thirty-landmark data consisted of a skeletal and a dental group represented by twenty and eight landmarks respectively. The skeletal group's total amount of change is measured with 34.18 PDU. Thus

representing 49.33% of the total change in the 6-11 age group. Within the skeletal group, Nasion moved the least with 0.402 PDU (0.58%) in an anterior direction while Supradentale moved the most with 2.736 PDU (3.95%) downward and forward. The dental group measured 35.11 PDU, which represented 50.67% of the total observed change within the age period. Dentally, Lower Incisor Edge moved the least with 2.146 PDU (3.1%) anteriorly and the Upper Central Incisor Root Apex Left moved the most with 8.172 PDU (11.8%) in a superior, posterior, and medial direction.

The magnification in order to allow the Procrustes superimposition for the Class II, Division 1 S/D Bolton female for the age period 6-11 was 1.006785. What this means is that a six-year-old Class II, Division 1 S/D Bolton female must be magnified 0.68% to be the same size as an eleven-year-old Class II, Division 1 S/D Bolton female (Table 4). The S group amount of magnification for the period 6-11 was 1.007792. What this means is that a six-year-old Class II, Division 1 S Bolton female must be magnified 0.78% to be the same size as an eleven-year-old Class II, Division 1 S Bolton female (Table 4).

4.1.2 SIZE DIFFERENCE OF CLASS I AGE 6-11

The magnification in order to allow the Procrustes superimposition for the Class I S/D Bolton female for the age period 6-11 was 1.105085. What this means is that a six-year-old Class I S/D Bolton female must be magnified 10.5% to be the same size as an eleven-year-old Class I S/D Bolton female (Table 4). The S group amount of magnification for the Class I Bolton female Standard for the period 6-11 was 1.103453. What this means is that a six-year-old Class I S Bolton female must be magnified 10.3% to be the same size as an eleven-year-old Class I S Bolton female (Table 4).

4.1.3 CLASS II, DIVISION 1 AGE 11-15

In the S/D group, the Class II, Division 1 11-15 year age period exhibited an overall shape change total of 46.044 PDU (Figure 8). The skeletal landmarks had a total change of 29.699 PDU, which is 64.5% of the overall change. The dental landmarks moved 16.345 PDU or 35.5% of the total shape change for the age period. The dental landmark that exhibited the most change was the Upper First Molar Right with 4.212 PDU (9.15%) in a downward, forward, and medial direction. The Upper Incisal Edge was least with 0.176 PDU (0.38%) in a directly inferior

movement. Skeletally, Basion moved the most with 2.397 PDU (5.2%) superiorly and slightly anteriorly while B Point moved the least with 0.330 PDU (0.71%) inferiorly and slightly posterior. Overall, the Upper Incisal Edge moved the least with 0.176 PDU (0.38%) inferiorly and the Upper First Molar Right had the greatest amount of change with 4.212 PDU (9.15%) downward, forward, and medially.

In the twenty-two-landmark group (S) for the age period 11-15 years, there was 23.367 PDU of overall shape change (Figure 9). Supradentale changed the least with 0.142 PDU (0.6%) and Basion changed the most with 2.009 PDU (8.6%). Basion changed the most for both S and S/D groups.

The magnification in order to allow the Procrustes superimposition for the Class II, Division 1 S/D Bolton female for the age period 11-15 was 1.06518. What this means is that an eleven-year-old Class II, Division 1 S/D Bolton female must be magnified 6.5% to be the same size as a fifteen-year-old Class II, Division 1 S/D Bolton female (Table 4). The S group amount of magnification for the period 11-15 was 1.067205. What this means is that an eleven-year-old Class II, Division 1 S Bolton

female must be magnified 6.72% to be the same size as a fifteen-year-old Class II, Division 1 S Bolton female (Table 4).

4.1.4 SIZE DIFFERENCE OF CLASS I AGE 11-15

The magnification in order to allow the Procrustes superimposition for the Class I S/D Bolton female for the age period 11-15 was 1.05455. What this means is that an eleven-year-old Class I S/D Bolton female must be magnified 5.45% to be the same size as a fifteen-year-old Class I S/D Bolton female (Table 4). The S group amount of magnification for the Class I Bolton female Standard for the period 11-15 was 1.059221. What this means is that an eleven-year-old Class I S Bolton female must be magnified 5.92% to be the same size as a fifteen-year-old Class I S Bolton female (Table 4).

4.1.5 CLASS II, DIVISION 1 AGE 6-15

Examining the S/D 6-15 year group reveals a total shape change measured with 83.907 PDU (Figure 10). Overall, Nasion moved the least with 0.611 PDU (0.73%) posterior, and the Central Incisor Root Apex Left moved the most with 8.551 PDU (10.2%) in a superior, posterior, and medial direction. Within the S/D group, the skeletal group was 49.484 PDU or 58.97% of the total. The dental

change was 34.423 PDU or 41.03%. The Lower Incisal Edge changed the least with 1.720 PDU (2.05%) in an anterior and slightly inferior direction and Central Incisor Root Apex Left moved the most with 8.551 PDU (10.2%) superiorly, posteriorly, and medially. Skeletally, Nasion moved the least with 0.611 PDU (0.73%) and Sella exhibited the most change with 3.574 PDU (4.26%) superiorly and anteriorly.

Examining the S group revealed 49.865 PDU of overall shape change for the 6-15 year period (Figure 11). PNS changed the least with 1.102 PDU (2.2%) and Orbitale Left changed the most with 3.574 PDU (7.16%).

The magnification in order to allow the Procrustes superimposition for the Class II, Division 1 S/D Bolton female for the age period 6-15 was 1.072845. What this means is that a six-year-old Class II, Division 1 S/D Bolton female must be magnified 7.28% to be the same size as a fifteen-year-old Class II, Division 1 S/D Bolton female (Table 4). The S group amount of magnification for the period 6-15 was 1.075188. What this means is that a six-year-old Class II, Division 1 S Bolton female

must be magnified 7.51% to be the same size as a fifteen-year-old Class II, Division 1 S Bolton female (Table 4).

4.1.6 SIZE DIFFERENCE OF CLASS I AGE 6-15

The magnification in order to allow the Procrustes superimposition for the Class I S/D Bolton female for the age period 6-15 was 1.165806. What this means is that a six-year-old Class I S/D Bolton female must be magnified 16.58% to be the same size as a fifteen-year-old Class I S/D Bolton female (Table 4). The S group amount of magnification for the Class I Bolton female Standard for the period 6-15 was 1.168187. What this means is that a six-year-old Class I S Bolton female must be magnified 16.81% to be the same size as a fifteen-year-old Class I S Bolton female (Table 4).

4.1.7 CLASS II vs. CLASS I AGE SIX

Comparing the Class II, Division 1 Bolton females to the Class I Bolton females at age six years revealed a total shape change of 55.982 PDU in the Class II S/D sample comparatively (Figure 18). In the S/D group, the landmark with the least difference from the Class II to Class I sample was the Lower First Molar Left with a difference of 0.155 PDU (0.27%) inferiorly, posteriorly,

and medially. Mechanical Porion Left exhibited the greatest difference of 4.569 PDU (8.16%) inferior and medial. The skeletal component of the S/D group had a total shape change measured to be 43.81 PDU or 78.25% of the overall change. Orbitale Right was the least with 0.542 PDU (0.97%) medially, inferiorly, and anteriorly in the skeletal group while Mechanical Porion Left had the largest difference of 4.569 PDU (8.16%). Dentally, the Lower First Molar Left had the least change with 0.155 PDU (0.27%) and the Central Root Apex Left showed the most change with 3.001 PDU (5.36%) superiorly, posteriorly, and medially.

Comparing the Class II, Division 1 to Class I female in the S group showed a total shape difference of 43.732 PDU (Figure 19). PNS changed the least with 0.497 PDU (1.14%) and Mechanical Porion Left changed the most with 4.652 PDU (10.64%). Mechanical Porion Left changed the most for both S and S/D groups while PNS and Orbitale Right swapped spots for the least change in both groups.

The magnification in order to allow the Procrustes superimposition for the Class II, Division 1 S/D Bolton female compared to the Class I S/D Bolton Standard for

age six was 1.096009. This means that a Class II, Division 1 S/D Bolton female is 9.6% larger than a Class I S/D Bolton female at age six (Table 4). The S group amount of magnification for Class II, Division 1 Bolton female to Class I Bolton female at age six was 1.096606. This means that a Class II, Division 1 S Bolton female is 9.66% larger than a Class I S Bolton female at age six (Table 4).

4.1.8 CLASS II vs. CLASS I AGE ELEVEN

The age eleven S/D group exhibited an overall shape difference total of 52.984 PDU between the Class II and Class I sample (Figure 20). The skeletal component accounted for a difference of 42.781 PDU or 81% of the total difference. The dental landmarks were 10.203 PDU or 19% of the total difference between Class II and Class I at age eleven years. Overall, Upper Incisal Edge had the least difference with 0.244 PDU (0.46%) anterior and inferior and Mechanical Porion Right showed the biggest difference with 3.523 PDU (6.65%) between the groups. Mechanical Porion Right was located inferiorly and medial to the Standard. Skeletally, Orbitale Left had the least difference with 0.410 PDU (0.77%) inferior and medial, while Mechanical Porion Right had the largest difference

of 3.523 PDU (6.65%) inferior and medial. In the dental group, the Upper Incisal Edge demonstrated the least difference with 0.244 PDU (0.46%) anterior and inferior, while the Central Incisor Root Apex Right had the greatest difference of 3.036 PDU (5.73%) in an anterior and lateral direction.

In the S group for age eleven, comparing Class II to Class I, there was 42.224 PDU of total shape difference (Figure 21). PNS exhibited the least change with 0.355 PDU (0.84%) while Mechanical Porion Left had the most change with 3.597 PDU (8.52%). There was a slight difference between the S and S/D groups for the least movement. Orbitale Left and PNS switched spots of first and second between the groups. Mechanical Porion Right changed the most for both S and S/D groups.

The magnification in order to allow the Procrustes superimposition for the Class II, Division 1 S/D Bolton female compared to the Class I S/D Bolton Standard for age eleven was 1.00030. This means that a Class II, Division 1 S/D Bolton female is 0.03% larger than a Class I S/D Bolton female at age eleven (Table 4). The S group amount of magnification for Class II, Division 1 Bolton

female to Class I Bolton female at age eleven was 1.001487. This means that a Class II, Division 1 S Bolton female is 0.15% larger than a Class I S Bolton female at age eleven (Table 4).

4.1.9 CLASS II vs. CLASS I AGE FIFTEEN

Comparing at age fifteen years gave a total shape difference of 60.617 PDU between the Class II, Division 1 females and the Bolton Standards for thiry landmarks (Figure 22). Skeletal components accounted for 46.827 PDU or 77.25% of the total difference while the dental components were 13.79 PDU or 22.75% of the total. Overall, PNS had the least difference between Class II and Class I with 0.439 PDU (0.72%) in an inferior position. Pogonion demonstrated the largest shape difference with a difference of 4.227 PDU (6.97%) in a posterior position. Dentally, the Lower First Molar Right had the least difference of 0.550 PDU (0.9%) inferior, anterior, and medial, while the Upper First Molar Left had the largest difference of 3.088 PDU (5.1%) in lateral and anterior direction. Finally, within the skeletal group, PNS had the least difference of 0.439

(0.72%) PDU inferiorly, and Pogonion demonstrated the largest difference of 4.227 PDU (6.97%) posteriorly.

The twenty-two-landmark (S) group for age fifteen exhibited 44.877 PDU of overall shape change between Class II and Class I (Figure 23). Orbitale Left changed the least with 0.281 PDU (0.62%) and Rhinion changed the most with 4.375 PDU (9.75%).

The magnification in order to allow the Procrustes superimposition for the Class II, Division 1 S/D Bolton female compared to the Class I S/D Bolton Standard for age fifteen was 1.010637. This means that a Class II, Division 1 S/D Bolton female is 1.06% larger than a Class I S/D Bolton female at age fifteen (Table 4). The S group amount of magnification for Class II, Division 1 Bolton female to Class I Bolton female at age fifteen was 1.008825. This means that a Class II, Division 1 S Bolton female is 0.88% larger than a Class I S Bolton female at age fifteen (Table 4).

4.2 CRANIAL VAULT

The following landmarks represent the cranial vault: Nasion, Sella, Basion, Mechanical Porion L/R, Orbitale L/R, and Medial Orbit L/R.

4.2.1 CLASS II, DIVISION 1 AGE 6-11

In the Class II, Division 1 S/D sample during the age period 6-11 years there was a combined change of 11.55 PDU or 16.67% of the total change for this age period (Figure 6). Skeletally, Sella change the most with 2.254 PDU (3.25%) superiorly and anteriorly. Nasion changed the least with 0.402 PDU (0.58%) directly anteriorly. Dentally, Lower Incisor Edge moved the least at 2.146 PDU (3.1%) anteriorly, while Central Incisor Root Apex Left moved the most with 8.172 PDU (11.8%) superiorly and posteriorly. Overall, Nasion moved slightly anteriorly, Sella moved superiorly and anteriorly, Basion moved slightly anteriorly as did the Mechanical Porions. Orbitale Left/Right moved posterosuperiorly and Medial Orbit Right/Left moved inferiorly and posteriorly.

Comparing the Class II S/D sample to the Class I S/D for the period 6-11 years shows similar findings for the cranial vault. The Class I group changed 12.668 PDU or 18.66% of the total change for this period (Figure 12). While the Class II changed 11.55 PDU or 16.67% (Figure 6), Nasion changed the least in both the Class I and

Class II samples. Interestingly, Basion moved the most for the Class I group and Sella the most in the Class II sample.

In the S group for the age period 6-11 years, the cranial vault contributed 12.772 PDU or 40.37% to the overall shape change (Figure 7). Mechanical Porion Right changed the least with 0.660 PDU (2.08%) anteriorly and Orbitale Left changed the most with 2.711 PDU (8.57%) posterosuperiorly.

4.2.2 CLASS II, DIVISION 1 AGE 11-15

In the S/D group for the age period 11-15, there was 13.121 PDU change in the cranial vault (Figure 8). The change represents 28.5% of the overall craniofacial change for the Class II, Division 1 female during this age period. Nasion changed the least with 0.944 PDU (2.05%) in a slightly inferior and posterior direction. Basion exhibited the most change with 2.397 PDU (5.2%) in a slightly superoanterior direction.

In the Class II S group for the age period 11-15, there was 9.682 PDU change in the cranial vault (Figure 9). The change represents 41.43% of the overall craniofacial change for the Class II, Division 1 female

during this age period. Orbitale Left changed the least with 0.602 PDU (2.57%) in an inferoposterior and medial direction. Basion exhibited the most change with 2.009 PDU (8.6%) in a slightly superoanterior direction.

4.2.3 CLASS II, DIVISION 1 AGE 6-15

In the Class II, Division 1 S/D group for the age period 6-15, there was 22.36 PDU change in the cranial vault (Figure 10). The change represents 26.65% of the overall craniofacial change for the Class II, Division 1 female during this age period. Nasion changed the least with 0.611 PDU (0.73%) in a slightly posterior direction. Sella exhibited the most change with 3.574 PDU (4.26%) in a slightly superoanterior direction.

In the Class II, Division 1 S group for the age period 6-15, there was 22.256 PDU change in the cranial vault (Figure 11). The change represents 44.63% of the overall craniofacial change for the Class II, Division 1 female during this age period. Nasion changed the least with 1.13 PDU (2.26%) in a slightly posterior direction. Orbitale Left exhibited the most change with 3.48 PDU (6.97%) in a slightly superoposterior and medial direction.

4.2.4 CLASS II vs. CLASS I AGE SIX

The difference between the Class II and Class I S/D groups at age six in the cranial vault was 20.972 PDU or 37.46% of the total difference of the craniofacial regions (Figure 18). Mechanical Porion Right had the most difference with 4.569 PDU (8.16%) and Orbitale Right exhibited the least difference between the groups for this age with 0.542 PDU (0.97%). Mechanical Porions for the Class II group were located inferior and medial to the Class I homologous landmark. Orbitale Right in the Class II was located superior and medial to its Class I counterpart.

The difference between the Class II and Class I S groups at age six in the cranial vault was 19.27 PDU or 44.1% of the total difference of the craniofacial regions (Figure 19). Mechanical Porion Left exhibited the most difference with 4.652 PDU (10.63%) and Orbitale Right exhibited the least difference between the groups for this age with 0.703 PDU (1.6%). Mechanical Porions for the Class II group were located inferior and medial to the Class I homologous landmark. Orbitale Right in the

Class II was located superior and medial to its Class I counterpart.

Comparing the Class II, Division 1 S/D and S groups to the Class I S/D and S groups at age six years shows Nasion, Sella, and the Medial Orbits in the Class II positioned more superiorly. Basion is more anterior and the Mechanical Porions Right/Left and Orbitale Right/Left are more inferior positioned compared to the Class I sample.

4.2.5 CLASS II vs. CLASS I AGE ELEVEN

The difference between the Class II and Class I S/D groups at age eleven in the cranial vault was 16.57 PDU or 31.3% of the total difference of the craniofacial regions (Figure 20). Mechanical Porion Right had the most difference with 3.523 PDU (6.64%) and Orbitale Left exhibited the least difference between the groups for this age with 0.41 PDU (0.77%). Mechanical Porions for the Class II group were located inferior and medial to the Class I homologous landmark. Orbitale Right in the Class II was located superior and medial to its Class I counterpart.

In the S sample comparing Class II to Class I at age eleven (Figure 21), there was a difference of 17.353 PDU between the two samples in the cranial vault, which represents 41.1% of the total shape difference for this age. Mechanical Porion Right had the greatest difference between the two groups with 3.597 PDU (8.52%). Orbitale Left exhibited the least difference at age eleven with 0.522 PDU (1.23%). Mechanical Porions for the Class II group were located inferior and medial to the Class I homologous landmark. Orbitale Right in the Class II was located superior and medial to its Class I counterpart.

4.2.6 CLASS II vs. CLASS I AGE FIFTEEN

The difference between the Class II and Class I S/D groups at age fifteen in the cranial vault was 12.098 PDU or 20% of the total difference of the craniofacial regions (Figure 22). Mechanical Porion Right had the most difference with 4.204 PDU (6.93%) and Medial Orbitale Left exhibited the least difference between the groups for this age with 0.766 PDU (1.26%). Mechanical Porions for the Class II group were located inferior and medial to the Class I homologous landmark. Orbitale

Right in the Class II was located superior and medial to its Class I counterpart.

The difference between the Class II and Class I S groups at age fifteen in the cranial vault was 16.371 PDU or 36.5% of the total difference of the craniofacial regions (Figure 23). Mechanical Porion Right had the most difference with 4.345 PDU and Orbitale Left exhibited the least difference between the groups for this age with 0.281 PDU. Mechanical Porions for the Class II group were located inferior and medial to the Class I homologous landmark. Orbitale Right in the Class II was located superior and medial to its Class I counterpart.

4.3 MIDFACE

The following landmarks represent the midface group: Nasion, Rhinion, L/R Piriform, and Anterior Nasal Spine (ANS).

4.3.1 CLASS II, DIVISION 1 AGE 6-11

During the 6-11 age period, the Class II S/D group midface changed 8.29 PDU or 11.96% of the total shape change (Figure 6). Comparatively, the Class I standard exhibited 7.158 PDU or 10.55% change in this region for

the same time period (Figure 12). In the Class II S/D sample Piriform R changed the most with 2.229 PDU (3.22%) in an inferior, lateral, and slightly anterior movement. Nasion moved the least with 0.402 PDU (0.58%) directly anterior. Compared to the Class I, similar results were seen. Piriform Right moved the most with 2.140 PDU (3.15%) in the Class I midface while Nasion changed the least with 0.054 PDU (0.08%). The Class II S/D midface landmarks were located relative to the Class I landmarks at age six (Figure 18) as follows: Nasion was superior and anterior; Rhinion was superior and anterior; Piriform Left/Right were inferior and lateral; and ANS was located superior and anterior to the Class I homologous landmarks.

In the S group for the age period 6-11 years (Figure 7), the midface contributed 6.721 PDU or 21.24% to the overall shape change. Nasion changed the least with 0.904 PDU (2.85%) and Piriform Right changed the most with 1.672 PDU (5.33%).

4.3.2 CLASS II, DIVISION 1 AGE 11-15

During the 11-15 age period, in the Class II S/D sample, the midface group exhibited 7.474 PDU or 16.23%

of total shape change (Figure 8). Comparatively, the Class I standard had 4.946 PDU or 11.18% of total change (Figure 14). The Class II midface exhibited the most change at Piriform Left with 2.074 PDU (4.5%) posteriorly and inferiorly and the least change at ANS with 0.529 PDU (1.15%) inferiorly and posteriorly. In the Class I group, Rhinion changed the least at 0.407 PDU (0.91%) anteriorly and inferiorly while Piriform Left moved the most with 1.3397 PDU (3.03%) posteriorly and inferiorly (Figure 14).

During the 11-15 age period, in the Class II S sample, the midface group exhibited 6.111 PDU or 26.15% of total change (Figure 9). Comparatively, the Class I S midface had 4.412 PDU of shape change, which contributed to 18.16% of the total shape change for the age period (Figure 15). The Cl II S midface exhibited the most change at Rhinion with 1.79 PDU (7.66%) inferposteriorly and the least change was at ANS with 0.437 PDU (1.87%) inferoposteriorly. In the Class I group (Figure 15), Nasion changed the least at 0.634 PDU (2.6%) while Piriform Left moved the most with 1.418 PDU (5.83%) posteroinferiorly.

4.3.3 CLASS II, DIVISION 1 AGE 6-15

During the age period 6-15, the Class II S/D sample exhibited 9.38 PDU or 11.18% of total shape change in the midface (Figure 10). Piriform Right changed the most with 2.823 PDU (3.36%) inferoposteriorly and lateral. Nasion changed the least with 0.611 PDU (0.73%) in a posterior direction. In the Class I sample, the midface contributed 9.62 PDU or 12.26% in the overall change from age 6-15 years (Figure 16). Nasion changed the least with 1.044 PDU (1.33%) and Piriform Left changed the most with 2.650 PDU (3.38%).

During the age period 6-15, the Class II S sample exhibited 10.015 PDU or 20.1% of total shape change in the midface (Figure 11). Piriform Right changed the most with 2.678 PDU (5.37%) inferoposteriorly and lateral. Nasion changed the least with 1.13 PDU (2.26%) in a posterior direction. In the Class I sample, the midface contributed 10.426 PDU or 21% in the overall change from age 6-15 years (Figure 17). Rhinion changed the least with 0.948 PDU (1.9%) and Piriform Left changed the most with 3.014 PDU (6.05%). Comparatively, at age fifteen, the Class II S group landmarks were related to the Class

I in the same relationship as the S/D group; Nasion, slightly superoanterior; Rhinion, superoanterior; Piriform Left/Right, inferoposteriorly; and ANS, anteriorly (Figure 23).

4.3.4 CLASS II vs. CLASS I AGE SIX

Comparing the Class II, Division 1 S/D sample to the Class I S/D at age six years showed a difference in the midface of 11.071 PDU between Class II and Class I (Figure 18). The difference represented 19.77% of the total difference in shape change at age six between Class II and Class I. Rhinion had the biggest difference between the groups with 3.104 PDU (5.54%). Piriform Left showed the least difference with 1.446 PDU (2.58%). At age six, the Class II midface landmarks were related to the Class I homologous landmark as follows: Nasion, superoanterior; Rhinion, superoanterior; Piriform Right/Left, anteroinferior; and ANS, superoanterior.

Comparing the Class II, Division 1 S sample to the Class I S group at age six years shows a total shape difference in the midface of 10.878 PDU between Class II and Class I (Figure 19). The difference represents 25% of the total difference in shape change at age six

between Class II and Class I. Rhinion had the biggest difference between the groups with 2.855 PDU (6.52%). ANS showed the least difference with 1.663 PDU (3.8%). At age six, the Class II midface landmarks were related to the Class I homologous landmark as follows: Nasion, superoanterior; Rhinion, superoanterior; Piriform Right/Left, anteroinferior; ANS, superoanterior.

4.3.5 CLASS II vs. CLASS I AGE ELEVEN

Comparatively, the Class II S/D group to the Class I S/D group at age eleven years had a difference of 11.052 PDU in the midface (Figure 20). The difference represented 21% of the total shape difference for age eleven. Nasion showed the largest difference between the groups with 3.101 PDU (5.85%), while Piriform Left had the least difference with 1.53 PDU (2.88%). Comparatively, the Class II group to the Class I group at age eleven years were positioned as follows: Nasion, superoanterior; Rhinion, superoanterior; Piriform Left/Right, inferiorly; and ANS was superoanterior to its homologous Class I counterpart.

The Class II S group to the Class I S group at age eleven years had a difference of 11.452 PDU in the

midface (Figure 21). The difference represented 27.1% of the total shape difference for age eleven. Nasion showed the largest difference between the groups with 3.21 PDU (7.6%) while Piriform Left had the least difference with 1.45 PDU (3.43%). The landmarks were the same as in the S/D group in terms of most and least change. The midface landmarks were positioned as follows: Nasion, superoanterior; Rhinion, superoanterior; Piriform Left/Right, inferiorly; and ANS was superoanterior to its homologous Class I counterpart.

4.3.6 CLASS II vs. CLASS I AGE FIFTEEN

Comparatively, the Class II S/D group to the Class I S/D group at age fifteen years had a difference of 11.405 PDU in the midface (Figure 22). The difference represented 18.8% of the total shape difference for age fifteen. Rhinion showed the largest difference between the groups with 4.019 PDU (6.63%) while Piriform Left had the least difference with 1.37 PDU (2.26%). The landmarks were the same as in the S/D group in terms of most and least change. The midface landmarks were positioned as follows: Nasion, superoanterior; Rhinion,

superoanterior; Piriform Left/Right, inferiorly; and ANS was superoanterior to its homologous Class I counterpart.

The Class II S group to the Class I S group at age fifteen years had a difference of 11.817 PDU in the midface (Figure 23). The difference represented 26.3% of the total shape difference for age fifteen. Rhinion showed the largest difference between the groups with 4.375 PDU (9.75%) while Piriform Left had the least difference with 0.942 PDU (2.1%). The landmarks were the same as in the S/D group in terms of most and least change. The midface landmarks were positioned as follows: Nasion, superoanterior; Rhinion, superoanterior; Piriform Left/Right, inferiorly; and ANS was superoanterior to its homologous Class I counterpart.

4.4 MAXILLA

The following landmarks represent the maxilla: Anterior Nasal Spine (ANS), Posterior Nasal Spine (PNS), A Point, and Supradentale.

4.4.1 CLASS II, DIVISION 1 AGE 6-11

In the Class II S/D group for the age period 6-11, the maxilla exhibited 8.764 PDU of shape change or 12.65% of the total shape change (Figure 6). Supradentale

changed the most with 3.608 PDU (5.2%) moving anterior and inferiorly. PNS changed the least with 1.496 PDU (2.16%) moving inferiorly. Comparatively, the Class I maxillary landmarks contributed 7.561 PDU or 11.14% to the overall change for the age period 6-11 (Figure 12). PNS moved the least with 1.243 PDU (1.83%) inferiorly. A Point changed the most at 2.241 PDU (3.3%) inferiorly and slightly posterior. As a group the Class II S/D landmarks were positioned as follows at age six compared to the Class I: ANS, superiorly and anteriorly; PNS, the same; A Point, slightly anteriorly; and Supradentale, superiorly and anteriorly (Figure 18).

In the Class II S group, the maxilla exhibited 7.126 PDU of shape change or 22.5% of the total shape change during the 6-11 year age period (Figure 7). A Point changed the most with 2.212 PDU (7%) moving posterior and inferiorly. PNS changed the least with 1.356 PDU (4.3%) moving inferiorly. Comparatively, the Class I S maxillary landmarks contributed 6.766 PDU or 20.7% to the overall shape change (Figure 13). PNS moved the least with 0.549 PDU (1.7%) inferiorly. A Point moved the most with 2.51 PDU (7.7%) inferior and posterior. As a group

the Class II S landmarks were positioned at age six compared to the Class I as follows: ANS, superiorly and anteriorly; PNS, the same; A Point, slightly anteriorly; and Supradentale, superiorly and anteriorly (Figure 18).

4.4.2 CLASS II, DIVISION 1 AGE 11-15

During the age period 11-15 years, the Class II S/D maxillary landmarks changed 3.2 PDU or 6.95% of the total change in the Class II sample (Figure 8). ANS moved the least with 0.529 PDU (1.15%) inferiorly and posteriorly. PNS moved the most with 0.989 PDU (2.15%) in a posterior direction. The Class I sample changed 4.804 PDU or 10.85% of the total change for this age period (Figure 14). Supradentale moved the least with 1.003 PDU (2.26%) inferiorly and posteriorly. A Point moved the most with 1.526 PDU (3.44) superiorly and posteriorly.

During the age period 11-15 years, the Class II S maxillary landmarks changed 1.506 PDU or 6.44% of the total change in the Class II sample (Figure 9). Supradentale moved the least with 0.142 PDU inferiorly. A Point moved the most with 0.54 PDU (2.31%) in a posteroinferior direction. The Class I sample changed 3.262 PDU or 13.4% of the total change for this age

period (Figure 15). PNS moved the least with 0.573 PDU (2.36%) posteriorly. A Point moved the most with 1.139 PDU (4.69%) superiorly and posteriorly.

4.4.3 CLASS II, DIVISION 1 AGE 6-15

During the 6-15 year age period, the Class II S/D maxillary landmarks exhibited 7.369 PDU of shape change (Figure 10). The maxillary landmark's change contributed 8.78% to the overall shape change for the period 6-15 years. Comparatively, in the Class I S/D sample, there was 5.515 PDU of maxillary shape change for the period 6-15 years of age (Figure 16), which was 7% of the total shape change for the age period. In the Class I S/D sample, PNS moved the least with 0.254 PDU (0.32%) and remained in virtually the same position throughout this period. A Point moved the most at 2.215 PDU (2.82%) inferiorly and posteriorly. In the Class II S/D sample Supradentale moved the most with 2.188 PDU (2.6%) anteriorly and inferiorly. PNS moved the least with 0.984 PDU (1.17%) inferiorly throughout the time period. At age fifteen, the Class II S/D maxillary landmarks were related to the Standards as follows: ANS, anterior and superior; PNS, slightly inferior; A Point, anterior and

inferior; and Supradentale, anterior and inferior (Figure 22).

During the 6-15 year age period, the Class II S maxillary landmarks exhibited 7.031 PDU of shape change (Figure 10). The maxillary landmarks change contributed 14.1% to overall shape change. Comparatively, in the Class I S sample, there was 6.023 PDU of maxillary shape change, which was 12.1% of the total shape change for the age period (Figure 17). PNS moved the least with 0.296 PDU (0.6%) and remained in virtually the same position throughout this period. A Point moved the most with 2.715 PDU (5.45%) inferiorly and posteriorly in the Class I S sample. In the Class II S sample, Supradentale moved the most with 2.228 PDU (4.46%) anteriorly and inferiorly. PNS moved the least with 1.102 PDU (2.2%) inferiorly throughout the time period. At age fifteen, the Class II S maxillary landmarks were located in relation to the Class I as follows: ANS, superior and anterior; PNS, slightly inferior; A Point, anterior and slightly inferior; and Supradentale, largely anterior and slightly inferior (Figure 23).

4.4.4 CLASS II vs. CLASS I AGE SIX

Comparing the Class II, Division 1 S/D sample to the Class I S/D at age six years showed a shape difference in the maxilla of 5.484 PDU between Class II and Class I S/D groups (Figure 18). This difference represents 9.8% of the total difference in shape at age six between Class II and Class I. Supradentale showed the largest difference between the groups with 2.117 PDU (3.78%) superoanterior. PNS exhibited the least difference between the Class II and Class I with 0.616 PDU (1.1%). As a group, at age six, the Class II S/D landmarks were positioned relative to the Class I as follows: ANS, superiorly and anteriorly; PNS, the same; A Point, slightly anterior; and Supradentale, superiorly and anteriorly.

Comparing the Class II, Division 1 S sample to the Class I S group at age six years showed a difference in the maxilla of 4.857 PDU between Class II and Class I (Figure 19). The difference represents 11.1% of the total difference in shape at age six between Class II and Class I. Supradentale showed the largest difference between the groups with 1.948 PDU (4.45%) superoanterior. PNS exhibited the least difference with 0.497 PDU

(1.13%). As a group, at age six, the Class II S landmarks were positioned relative to the Class I as follows: ANS, superiorly and anteriorly; PNS, the same; A Point, slightly anterior; and Supradentale, superiorly and anteriorly.

4.4.5 CLASS II vs. CLASS I AGE ELEVEN

Comparatively, at age eleven, there was 6.105 PDU shape difference between the maxillary landmarks in the Class II S/D and Class I S/D groups (Figure 20). The difference accounted for 11.5% of the total difference between the groups in shape at age eleven. Supradentale exhibited the largest difference with 2.308 PDU (4.35%) anteroinferior, while PNS showed the least difference with 0.587 PDU (1.1%) inferior. At age eleven, the Class II S/D maxillary landmarks were located in relation to the Class I as follows: ANS, superior and anterior; PNS, inferior; A Point, slightly anterior; and Supradentale, anterior and inferior.

Comparatively, at age eleven, there was 6.715 PDU shape difference between the maxillary landmarks in the Class II S and Class I S groups (Figure 21). The difference accounted for 16% of the total shape

difference between the groups at age eleven. Supradentale and ANS exhibited the most difference with 2.566 PDU (6.1%), and PNS showed the least difference with 0.355 PDU (0.84%). At age eleven, the Class II S maxillary landmarks were located in relation to the standards as follows: ANS, superior and anterior; PNS, inferior; A Point, slightly anterior; and Supradentale, anterior and inferior.

4.4.6 CLASS II vs. CLASS I AGE FIFTEEN

At age fifteen, in the Class II S/D group there was 6.366 PDU shape difference between the maxillary landmarks in the Class II S/D and Class I S/D groups (Figure 22). The difference accounted for 10.5% of the total shape difference between the groups at age fifteen. Supradentale exhibited the most difference with 2.533 PDU (4.18%) anteroinferior, and PNS showed the least difference with 0.439 PDU (0.72%) inferior. At age fifteen, the Class II S/D maxillary landmarks were related to the standard as follows: ANS, anterior and superior; PNS, slightly inferior; A Point, anterior and inferior; and Supradentale, anterior and inferior.

Comparatively, at age fifteen, in the Class II S group there was 8.287 PDU shape difference between the maxillary landmarks in the Class II S and Class I S groups (Figure 23). The difference accounted for 18.5% of the total shape difference between the groups at age fifteen. Supradentale exhibited the most difference with 3.153 PDU (7%) and PNS showed the least difference with 0.587 PDU (1.3%). At age fifteen, the Class II S maxillary landmarks were related to the Standard as follows: ANS, anterior and superior; PNS, slightly inferior; A Point, anterior and inferior; and Supradentale, anterior and inferior.

4.5 MANDIBLE

The landmarks that represent the mandibular region are listed as follows: Gonion L/R, Menton, Pogonion, B Point, and Infradentale.

4.5.1 CLASS II, DIVISION 1 AGE 6-11

Within the Class II S/D sample for the age period 6-11 years, the mandibular landmarks contributed 7.351 PDU of shape change or 10.6% to the overall shape change for this period (Figure 6). Within the Class I sample for the same age period, there was 10.552 PDU or 15.54%

contribution to overall shape change (Figure 12). In the Class II S/D sample, B Point moved the least with 1.285 PDU (1.85%) moving slightly superior and anterior. Menton contributed to the most shape change with 2.953 PDU (4.26%) moving anterior and inferior. In the Class I S/D sample, Gonion Left moved the least with 0.702 PDU (1.03%) inferiorly. Menton also contributed to the most movement with 3.890 PDU (5.73%) moving substantially anterior and inferior.

Within the Class II S sample for the age period 6-11 years, the mandibular landmarks contributed 7.296 PDU of shape change or 23.1% to the overall shape change (Fig. 7). Within the Class I sample for the same age period, there was 7.889 PDU or 24.2% contribution to overall shape change (Fig. 12). In the Class II S sample, B Point changed the most with 1.791 PDU (5.66%) moving slightly superior and anterior. Gonion Right contributed to the least shape change with 0.501 PDU (1.58%) moving posterior, inferior, and medial. In the Class I S sample, B Point moved the least with 0.118 PDU (0.36%) inferiorly. Menton contributed to the most movement with

3.075 PDU (9.42%) moving substantially anterior and inferior.

4.5.2 CLASS II, DIVISION 1 AGE 11-15

During the age period 11-15, the Class II S/D mandibular landmarks contributed to 5.904 PDU or 12.82% of overall shape change (Figure 8). Gonion Right moved the most with 1.379 PDU (3%) inferior and posterior. B Point moved the least with 0.33 PDU (0.71%) inferiorly. In the Class I S/D sample for the same age period, the mandibular landmarks contributed to 7.893 PDU or 17.83% of the total shape change (Figure 14). Infradentale moved the least with 0.239 PDU (0.53%) slightly inferior. Gonion Left moved the most with 2.164 PDU (4.88%) inferiorly and posteriorly.

During the age period 11-15, the Class II S group mandibular landmarks contributed to 7.344 PDU or 31.42% of overall shape change (Figure 9). Menton changed the most with 1.907 PDU (8.16%) inferiorly and anterior. B Point moved the least with 0.478 PDU (2.04%) inferiorly. In the Class I S sample for the same age period, the mandibular landmarks contributed to 8.651 PDU or 35.6% of the total shape change (Figure 15). Infradentale moved

the least with 0.193 PDU (0.8%) slightly inferior. Pogonion changed the most with 2.454 PDU (10.1%) inferior and anterior.

4.5.3 CLASS II, DIVISION 1 AGE 6-15

For the 6-15 year age period, the Class II S/D mandibular landmarks contributed 11.995 PDU or 14.3% to the overall shape change (Figure 10). Infradentale moved the least 1.376 PDU (1.63%) anteriorly and inferior. Menton moved the most with 2.929 PDU (3.5%) inferiorly and slightly anterior. In the Class I S/D sample, the mandibular region contributed 16.739 PDU or 21.33% to the overall shape change for the 6-15 age period (Figure 16). Within that period, Infradentale moved the least with 0.863 PDU (1.1%) anterior and inferior. Menton moved the most with 5.329 PDU (6.8%) anterior and inferior.

For the 6-15 year age period, the Class II S mandibular landmarks contributed 13.533 PDU or 27.14% to the overall shape change (Figure 11). Infradentale moved the least 1.591 PDU (3.2%) anteriorly and inferior. Menton moved the most with 3.322 PDU (6.66%) inferior and anterior. In the Class I S sample, the mandibular region contributed 16.537 PDU or 33.2% to the overall shape

change for the 6-15 age period (Figure 17). Within that period, B Point moved the least with 0.519 PDU (1.04%) slightly anterior and inferior. Menton changed the most with 5.037 PDU (10.1%) anterior and inferior.

4.5.4 CLASS II vs. CLASS I AGE SIX

At age six, there was 10.926 PDU of shape difference between the mandibular landmarks in the Class II S/D and Class I S/D groups (Figure 18). The difference accounted for 19.5% of the total difference between the groups in shape at age six. B Point exhibited the largest difference with 2.861 PDU (5.1%) and Menton exhibited the least difference with 0.972 PDU (1.73%). The Class II S/D landmarks were related to the Class I S/D landmarks for this region as follows: Gonion Left/Right, posteriorly and medial; Menton, inferiorly; Pogonion, slightly posterior; B Point, largely posterior and inferior; and Infradentale, posteriorly.

Comparatively, at age six, there was 11.283 PDU of shape difference between the mandibular landmarks in the Class II S and Class I S groups (Figure 19). The difference accounted for 26% of the total difference between the groups in shape at age six. B Point

exhibited the largest difference with 3.053 PDU (6.98%) and Menton exhibited the least difference with 1.172 PDU (2.67%). The Class II S landmarks were related to the Class I S landmarks for this region as follows: Gonion Left/Right, posteriorly and medial; Menton, inferior and posterior; Pogonion, posterior and superior; B Point, largely posterior and inferior, and Infradentale, posteriorly.

4.5.5 CLASS II vs. CLASS I AGE ELEVEN

At age eleven, there was 14.456 PDU of shape difference between the mandibular landmarks in the Class II S/D and Class I S/D groups (Figure 20). The difference accounted for 27.3% of the total difference between the groups in shape at age eleven. Gonion Left exhibited the largest difference with 3.105 PDU (5.86%) and Infradentale exhibited the least difference with 1.371 PDU (2.6%). At age eleven, the Class II S/D mandibular landmarks were related to their homologous Class I landmarks as follows: Gonion Left/Right, posterior; Menton, posterior and inferior; Pogonion, posterior; B Point, posterior and inferior; and Infradentale, was superior and posterior.

Comparatively, at age eleven, there was 10.317 PDU of shape difference between the mandibular landmarks in the Class II S and Class I S groups (Figure 21). The difference accounted for 24.4% of the total difference between the groups in shape at age eleven. Gonion Left exhibited the largest difference with 2.634 PDU (6.23%) and Infradentale exhibited the least difference with 1.223 PDU (2.9%). At age eleven, the Class II S mandibular landmarks were related to their homologous Class I landmarks as follows: Gonion Left/Right, posterior, Menton, posterior and inferior, Pogonion, posterior, B Point, posterior and inferior, and Infradentale, was superior and posterior.

4.5.6 CLASS II vs. CLASS I AGE FIFTEEN

At age fifteen, there was 15.505 PDU of shape difference between the mandibular landmarks in the Class II S/D and Class I S/D groups (Figure 22). The difference accounted for 25.5% of the total difference between the groups in shape at age fifteen. Pogonion exhibited the largest difference with 4.227 PDU (7%) and Infradentale exhibited the least difference with 1.288 PDU (2.12%). At age fifteen, the Class II S/D mandibular

landmarks were related to the standards as follows: Gonion Left/Righ, superior, posterior, and medial; Menton, largely posterior and inferior; Pogonion, largely posterior and inferior; B Point, largely posterior and inferior; and Infradentale, slightly posterior.

Comparatively, at age fifteen, there was 13.347 PDU of shape difference between the mandibular landmarks in the Class II S and Class I S groups (Figure 23). The difference accounted for 29.74% of the total difference between the groups in shape at age fifteen. Pogonion exhibited the largest difference with 3.455 PDU (7.7%) and Infradentale exhibited the least difference with 0.741 PDU (1.65%). At age fifteen, the Class II S mandibular landmarks were related to the standards as follows: Gonion Left/Right, superior, posterior, and medial; Menton, largely posterior and inferior; Pogonion, largely posterior and inferior; B Point, largely posterior and inferior; and Infradentale, slightly posterior.

5. DISCUSSION

The greatest amount of overall shape change occurs in the Class II S/D sample between the ages 6-11 with 69.287 PDU. Of the total, 34.179PDU or 49.33% is skeletal while 35.108 PDU or 50.67% is dental shape change. The majority of the eruption of the permanent dentition corresponds to this age period. For the Class II S sample, the age period 6-11 also has the greatest amount of shape change with 31.635 PDU overall. In the 11-15 S/D age period, the overall shape change is 46.044 PDU with 29.699 PDU or 64.5% being skeletal change and 16.345 PDU or 35.5% being dental change. The Class II S sample for age 11-15 showed 23.367 PDU of shape change. Similarly, for the Class I S/D Standards, the overall shape change for the 6-11 age group was 67.863 PDU with 35.796 or 52.75% being skeletal and 32.067 PDU or 47.25% representing dental change. The Class I S sample had 32.639 PDU of shape change in the period 6-11 which was the greatest period in overall shape change. In both Class II and Class I, Nasion changed the least and Menton

the most in the Class I group with Supradentale the most in the Class II sample.

For the age period 11-15, the Class I S/D sample had total shape change measured at 44.275 PDU with 28.208 PDU or 63.71% being skeletal change and 16.067 PDU or 36.29% representing dental change. These numbers are almost identical for both samples. However, in the Class I S/D sample, Infradentale changed the least 0.239 PDU between 11-15. In the Class II S/D sample, Lower Incisal Edge changed the least with 0.176 PDU. In the Class I S/D, Upper First Molar Left changed the most with 3.397 PDU and similarly, in the Class II S/D, Upper First Molar Right changed the most with 4.212 PDU. The Class I S sample had 24.287 PDU of shape change for the age period 11-15.

Comparing the position of the landmarks in the Class II sample to the Standards at age six reveals a longer facial pattern with components of the cranial vault such as Nasion, Rhinion, and Sella being more superiorly positioned than the homologous Class I landmark. The midface is also superiorly related except for Piriform Right/Left being inferiorly positioned. In the maxilla, all Class II landmarks are anterior or protrusive to the

Class I counterpart except for PNS which is the same. In the mandible, Gonion Left/Right, Pogonion, and Infradentale are posteriorly related at age six to the Class I. B Point is significantly retrusive in the Class II and Menton is slightly inferior. Dentally, at age six, the maxillary dental landmarks are more anterior and the mandibular dental landmarks are more retruded compared to the Class I.

For age eleven, the cranial vault exhibits Nasion and Sella similar to age six position with Basion now related inferior and anterior to the Class I Basion. Mechanical Porion Left/Right, and Orbitale Left/Right are inferiorly positioned. Medial Orbit Left/Right is slightly superiorly positioned as it was at age six. In the midface, the same relationship exists for the Class II landmarks as at age six. In the maxilla at age eleven, ANS is anterior and superior, PNS has changed to a slightly inferior position, A Point is still anterior, and Supradentale is now anterior and inferior to the Class I homologous landmarks. In the mandible, the same pattern as existed at age six is prevalent, primarily retrusive positioning. However, Menton is now more

inferiorly posterior and Infradentale has moved superoposterior to the Class I.

Finally, at age fifteen, the same relationship of the cranial vault landmarks exists as at age eleven. Nasion is slightly superior and anterior and Sella is almost the same. Basion is positioned inferior and anterior. Mechanical Porions Left/Right are inferior, and Orbitale Left/Right are inferior posterior. Medial Orbits Left/Right are slightly posterior in the Class II group. The midface has the same relationship as age eleven. The maxilla also has the same relationship to the Class I as age eleven, protrusive, with PNS inferior. The mandibular landmarks exhibit a change at Gonion Right/Left from age eleven. Gonion Right/Left is now more superiorly posterior than the Class I. Menton, Pogonion, and B Point are significantly posterior and inferior to their homologous landmark in the Class I sample.

Dentally, following the maxillary first molars from age six, eleven, to fifteen reveals a shift of the molars anteriorly and medially observed in the anteroposterior and axial planes. In the Class II sample at all ages, there is more maxillary dental protrusion as well as

skeletal maxillary landmark protrusion compared to the Class I.

There appears to be a tipping of the palatal plane (ANS-PNS) up and forward at ANS and slightly inferior at PNS throughout the age periods. Gonion Right/Left are superior and posterior in the Class II and the mandibular landmarks are posteriorly located in relation to the Class I. It should be noted that for all age periods, the Mechanical Porions Right/Left were largely inferiorly and medially positioned compared to the Class I. Basion also exhibited this same pattern in the Class II except at age six where the Class II Basion was superior and anterior to the Class I Basion.

Overall, the cranial base landmarks as well as Nasion in the Class II are significantly different from the Class I. The orbits and maxillary molars appear to be located more medially than the Class I landmarks. During the age period 6-11, Class II and Class I overall shape change was 69.287 and 67.823 PDU respectively. Comparing the Class II to the Class I reveals 2% more change in the cranial vault than the Class I, 1.5% more in the midface and maxilla, and 5% less in the Class II mandibular region. For age 11-15, the cranial vault

change was the same percentage of total change, the midface of the Class II contributed to 5% more change to overall, the maxilla had 4% less change than the Class I, and the mandibular region had 5% less contribution to overall change than the Class I. From age 6-15, the cranial vaults were basically the same. The Class II midface was 1% less than the Class I contribution. The Class II maxilla was 1.78% more than the Class I in overall shape change. Finally, the mandible contributed 7% more to overall change in the Class I than the Class II sample. The Class II did have 83.907 PDU versus 78.445 PDU in overall shape change in the 6-15 period.

5.1 RESULTS COMPARISON TO THE LITERATURE

The results of the present study are compared to the literature's findings. In 1986, Buschang et al. used orthogonal polynomials to evaluate craniofacial growth of adolescent boys from eleven to fourteen years old with normal occlusion and Class II malocclusion. Buschang et al. found that the groups were comparable in growth velocity and acceleration, therefore indicating that the size differences were established before eleven years of age and maintained during adolescence. The present study's results agree with Buschang et al. (1986). The

size difference between a six-year-old Class II, Division 1 S/D Bolton female and a six-year-old Class I Bolton S/D female is 9.6%, with the Class II being 9.6% larger than the Class I. At age eleven, the size difference between the Class I Bolton female and the Class II, Division 1 Bolton female drops to only 0.03%, with the Class II female being slightly larger. By age fifteen, the size difference between the Class I and Class II is 1.06% with the Class II still larger than the Class I Bolton female. Therefore, the present study's findings are that, for the sample used, the size difference between the Class I Bolton female and the Class II, Division 1 Bolton female is established before age eleven and is maintained through adolescence (Table 4).

The shape differences between the Class I S/D Bolton female and the Class II, Division 1 S/D Bolton female also correspond with the greatest amount of shape change occurring between 6-11 years old. After eleven years of age, the mandibular landmarks contribute less to the overall shape change in the Class II, Division 1 S/D sample (Table 2).

In another study by Buschang et al. (1988), longitudinal mandibular growth of French-Canadian

children between ages six and fifteen years old with normal occlusion and untreated Class II, Division 1 malocclusion was compared. The findings indicated that with the exception of annual growth velocity, the curves describing the amount and direction of growth for the cephalometric landmark Gnathion were comparable for children with normal and Class II malocclusion. It was also found that girls and boys with a Class II, Division 1 malocclusion exhibited a consistent tendency for a more vertical growth direction, which would further increase anteroposterior jaw discrepancies. The findings of the present study support these results of Buschang et al.'s (1988) work.

In 1995, Pollard and Mamandras, reported that there existed a similarity in mean growth changes between males with Class I and II malocclusion in the post-pubertal development. The findings of the present study indicate that the size changes between ages eleven and fifteen in the female sample are similar while the shape differences are different. Comparing the Class II S/D Bolton female to the Class I Bolton female for the age period 11-15 reveals differences in shape. Comparing the Class II sample to the Class I shows an almost equal contribution

in cranial vault, 28.5% to 28.64% (Class II to Class I). In the midface, the Class II S/D sample contributed 16.23% compared to the Class I with 11.18%. In the maxilla, the Class I S/D had 10.85% of shape change contributing to the overall for the period 11-15 years, while the Class II had 6.95% of maxillary shape change contribution to overall change for the same period. In the mandible, the Class I showed 17.83% of shape change contribution to the overall for age 11-15, contrasting with the Class II's contribution of 12.82% shape change to overall for the same age period. The dental contributions to overall shape change was fairly equal with 36.29% and 35.5% Class I to Class II respectively (Table 2).

Finally, the transverse discrepancies between untreated Class I and Class II, Division 1 malocclusion groups was examined by Bishara et al. (1996). Bishara et al. found that the male and female Class I sample had a greater intermolar arch width than the Class II, Division 1 malocclusion sample. The findings also indicated that the relative constriction of the maxillary arch, as related to the mandibular arch, in the Class II, Division 1 malocclusion sample was expressed from the earliest

stages of dental arch development. Additionally, the proposed trend continued in the mixed dentition and early permanent dentitions, and did not self correct without treatment. The present study supports these findings by noting a continuous anterior and medial shift of the maxillary molars from age six to fifteen. In the Class II, Division 1 S/D Bolton female sample, the maxillary intermolar width was less than the Class I S/D Bolton Standards. However, the results were not statistically tested in order to establish statistical significance. The statements made are based on observation of the axial view of the SPLUS plots comparing Class II, Division 1 S/D Bolton females to Class I S/D Dolton females at ages six, eleven, and fifteen.

6. Conclusion

The development of the Broadbent-Bolton Cephalometer in 1925 has allowed the collection of biorthogonal cephalograms that could be interpreted through the Broadbent-Bolton Orientator into three-dimensional data collection for craniofacial growth and development. Up until the development of three-dimensional computer programs and digital imaging software, three-dimensional data collection for cephalometrics was laborious and difficult. The present study used computer technology to capture three-dimensional landmarks from sixteen untreated Bolton Class II, Division 1 female records. The Bolton-Brush Growth Study Center provided the radiographs that document the longitudinal craniofacial growth of the study participants.

The collection of three-dimensional landmark coordinates (x, y, and z) from the female Bolton images required the following steps: digital scanning of the cephalograms at the respective age groups of the sixteen Bolton females; the 3dCEPH© program was used to enhance

image quality; the 3dCEPH© program allowed three-dimensional landmark identification and co-registration of landmarks seen in both frontal and lateral cephalograms via a software implementation of the Broadbent-Bolton Orientator; and use of the Procfit© program to produce average landmarks from data sets collected for same-sex age groups (ages six, eleven, and fifteen).

A longitudinal measure of shape change was produced via the Procrustes algorithm. The Procrustes algorithm superimposes adjacent age group landmarks on a shared "centroid" via a least square fit. Individual landmark and overall Procrustes shape distances in Procrustes Distance Units (PDU) were calculated. To better analyze the observed shape change, the craniofacial complex was separated into the following four skeletal regions: Cranial vault, Mid-face, Maxilla, and Mandible. The dental landmarks were also evaluated for their contribution to overall shape change. However, the dental landmarks were separated from the skeletal landmarks in order to prevent the eruption of teeth from driving the data. The result was analysis of a thirty-

landmark group and a twenty-two-landmark group. Shape and size change was evaluated within the Class II, Division 1 Bolton Female sample for age period 6-11, 11-15, and 6-15 years. The average shape change for thirty and twenty-two landmark groups were analyzed for the age periods in the Class II sample as well as the Bolton Standard for Class I females. Additionally, the Class II shape and size data was compared to the Class I sample's shape and size data at the selected ages of six, eleven, and fifteen years.

Overall it can be seen that the craniofacial complex undergoes continuous shape change from ages 6-15 in the Class II S/D and S samples as well as in the Class I Standards.

The Bolton Class II, Division 1 female sample exhibited a longer facial pattern compared to the Class I Bolton female sample.

Comparing the Bolton female Class I sample to the Class II, Division 1 Bolton female sample revealed that the mandibular landmarks showed the smallest difference in shape at age six and the largest difference at age fifteen.

For the Class II sample, for ages 6-11, the mandibular landmarks contributed the least as a craniofacial region to the overall shape change.

The maxillary skeletal and dental landmarks are more protrusive in the Class II group at all age periods compared to the Class I sample.

The Class II, Division 1 Bolton female sample had the largest difference in size when comparing ages 11-15 (6.5%). However, for the Class I female sample, the largest size difference occurred when comparing ages 6-11 (10.5%).

At age six, the Class II, Division 1 Bolton female sample was 9.6% larger than the six-year-old Class I Bolton female sample. By age eleven, the difference in size decreased with the Class II sample being only 0.03% larger than the Class I Bolton female sample. At age fifteen, the Class I and Class II, Division 1 Bolton female samples were the same size.

The eventual addition of the male data should allow the three-dimensional information from the Bolton Study to contribute to diagnosis, treatment planning, prosthetic design, stereotactic procedures, and

procedural outcome assessments of the craniofacial patient.

APPENDIX

TABLE 2.—Comparison of contribution to overall shape change between Class I and Class II females for 30 LM data analysis

	Cl I			Cl II		
	Age 6-11	**Age 11-15**	**Age 6-15**	**Age 6-11**	**Age 11-15**	**Age 6-15**
Cranial Vault	18.66%	28.64%	27.4%	16.67%	28.5%	26.65%
Midface	10.55%	11.18%	12.26%	11.96%	16.23%	11.18%
Maxilla	11.14%	10.85%	7%	12.65%	6.95%	8.78%
Mandible	15.54%	17.83%	21.33%	10.6%	12.82%	14.3%
Dental	47.25%	36.29%	35.7%	50.67%	35.5%	41.03%

TABLE 3.—Comparison of contribution to overall shape change between Class I and Class II females for 22 LM data analysis

	Cl I			Cl II		
	Age 6-11	**Age 11-15**	**Age 6-15**	**Age 6-11**	**Age 11-15**	**Age 6-15**
Cranial Vault	41.66%	38.25%	41%	40.37%	41.43%	44.63%
Midface	22.27%	18.16%	21%	21.24%	26.15%	20.1%
Maxilla	20.7%	13.4%	12.1%	22.5%	6.44%	14.1%
Mandible	24.2%	35.6%	33.2%	23.1%	31.42%	27.14%

TABLE 4.—Magnification that occurred during the Procrustes superimposition

Intraoperator Reliability	30 LM	22 LM
T1-T2	**0.9969738**	
T2-T3	**1.0**	
T1-T3	**0.9986954**	
Class II Div 1		
6-11	**1.006785 (0.68%)**	**1.007792 (0.78%)**
11-15	**1.06518 (6.5%)**	**1.067205 (6.72%)**
6-15	**1.072845 (7.2%)**	**1.075188 (7.52%)**
Class I		
6-11	**1.105085 (10.5%)**	**1.103453 (10.3%)**
11-15	**1.05455 (5.4%)**	**1.059221 (5.9%)**
6-15	**1.165806 (16.5%)**	**1.168187 (16.8%)**
Cl I to Cl II Div1		
6	**1.096009 (9.6%)**	**1.096606 (9.66%)**
11	**1.00030 (0.03%)**	**1.001487 (0.15%)**
15	**1.010637 (1.06%)**	**1.008825 (0.88%)**

Landmarks
01. Sella
02. Basion
03. Mech Porion R
04. Mech Porion L
05. Nasion
06. Med Orbit R
07. Med Orbit L
08. Orbit-R
09. Orbit-L
10. Piriform-R
11. Piriform-L
12. Ant Nasal Spine
13. Post Nasal Spine
14. A-Point
15. Supradentale
16. U Incisal Edge
17. Upp MC-R
18. Upp MC-L
19. L Incisal Edge
20. Infradentale
21. Low MC-R
22. Low MC-L
23. B-Point
24. Pogonion
25. Menton
26. Gonion-R
27. Gonion-L
28. CenRoot-Apex-R
29. CenRoot-Apex-L
30. Rhinion

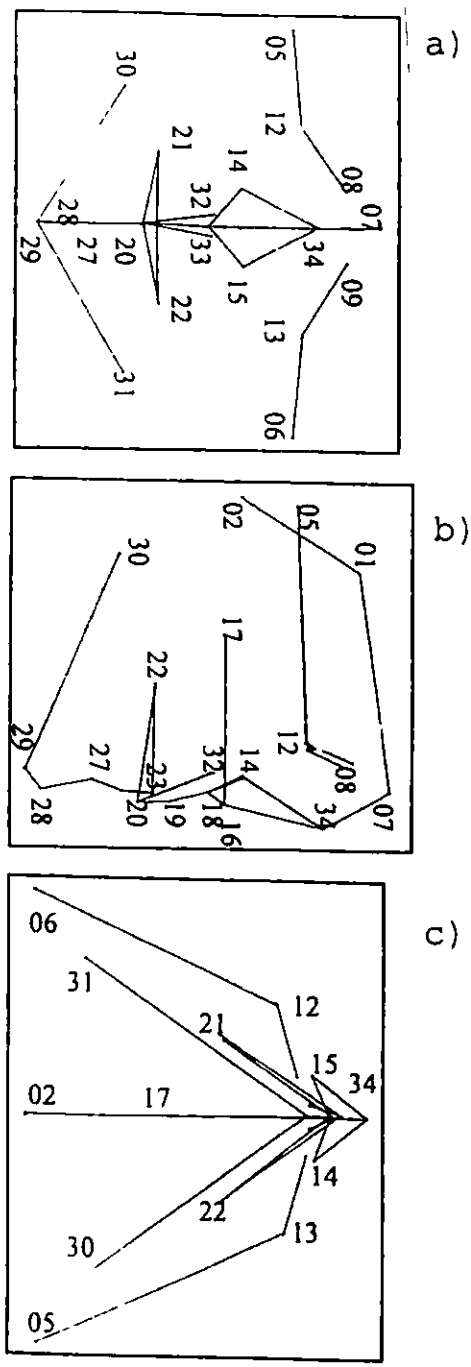


Figure 4. Landmarks used in the a)frontal, b)lateral, and c)axial views.

Rank	Labels	PDU
1	19.A_Point	0.255
2	25.Infradentale	0.287
3	26.Low_1st_Molar_R	0.297
4	28.B_Point	0.317
5	44.Rhinion	0.326
6	17.Ant_Nasal_Spine	0.365
7	24.Lower_Inc_Edge	0.365
8	30.Menton	0.391
9	35.Cen_Inc_RootApR	0.401
10	29.Pogonion	0.423
11	21.Upper_Inc_Edge	0.427
12	20.Supradentale	0.444
13	23.Upp_1st_Molar_L	0.460
14	14.Orbitale_L	0.485
15	22.Upp_1st_Molar_R	0.535
16	36.Cen_Inc_RootApL	0.560
17	13.Orbitale_R	0.596
18	05.Mech_Porion_L	0.597
19	00.Sella	0.619
20	04.Mech_Porion_R	0.642
21	06.Nasion	0.730
22	27.Low_1st_Molar_L	0.793
23	09.Medial_Orbit_R	0.824
24	18.Pos_Nasal_Spine	0.848
25	31.Gonion_R	0.957
26	10.Medial_Orbit_L	0.982
27	16.Piriform_L	1.132
28	32.Gonion_L	1.148
29	01.Basion	1.231
30	15.Piriform_R	1.370

Overall Aver: 0.627
Overall RMS : 0.278
Overall SD : 0.227

First Ten Aver: 0.343
First Ten RMS : 0.121
First Ten SD : 0.099

Last Ten Aver: 1.001
Last Ten RMS : 0.514
Last Ten SD : 0.419

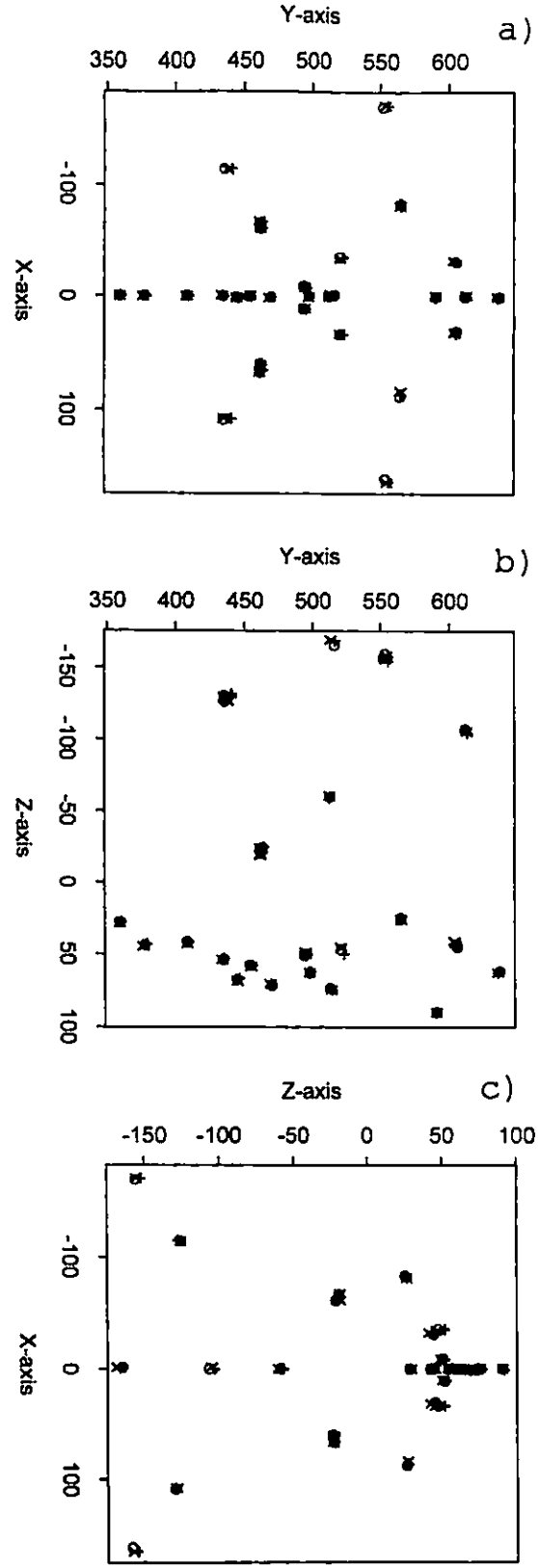


Figure 5. Procrustes Fit of landmarks comparing Intraoperator Reliability for Class II for Time 1, Time 2, and Time 3 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	31.Gonion_R	0.254
2	06.Nasion	0.402
3	32.Gonion_L	0.573
4	09.Medial_Orbit_R	0.842
5	13.Orbitale_R	0.913
6	10.Medial_Orbit_L	0.923
7	25.Infradentale	1.445
8	04.Mech_Porion_R	1.452
9	01.Basion	1.506
10	28.B_Point	1.531
11	05.Mech_Porion_L	1.629
12	17.Ant_Nasal_Spine	1.678
13	29.Pogonion	1.685
14	18.Pos_Nasal_Spine	1.830
15	30.Menton	1.863
16	16.Piriform_L	1.893
17	14.Orbitale_L	1.933
18	44.Rhinion	2.088
19	24.Lower_Inc_Edge	2.146
20	15.Piriform_R	2.229
21	00.Sella	2.254
22	19.A_Point	2.520
23	20.Supradentale	2.736
24	26.Low_1st_Molar_R	2.933
25	22.Upp_1st_Molar_R	3.352
26	23.Upp_1st_Molar_L	3.458
27	27.Low_1st_Molar_L	3.611
28	21.Upper_Inc_Edge	3.642
29	35.Cen_Inc_RootApR	7.794
30	36.Cen_Inc_RootApI	8.172

Overall Aver: 2.310
First Ten Aver: 0.984
Last Ten Aver: 4.047

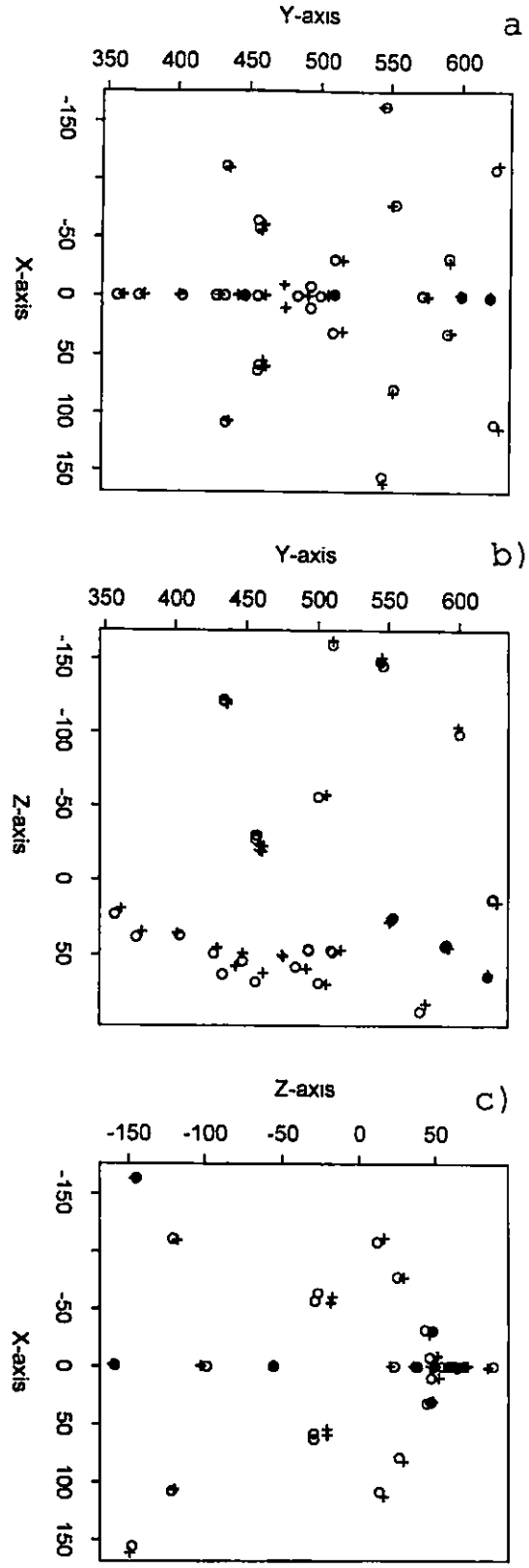


Figure 6. Procrustes Fit of landmarks comparing Class II from age:6 to age:11 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	31.Gonion R	0.501
2	04.Mech Porion R	0.660
3	01.Basion	0.865
4	06.Nasion	0.904
5	25.Infradentale	1.085
6	09.Medial Orbit R	1.139
7	32.Gonion L	1.162
8	29.Pogonion	1.281
9	16.Piriform L	1.321
10	05.Mech Porion L	1.352
11	18.Pos Nasal Spine	1.356
12	44.Rhinion	1.358
13	17.Ant Nasal Spine	1.376
14	30.Menton	1.476
15	10.Medial Orbit L	1.692
16	13.Orbitale R	1.703
17	00.Sella	1.746
18	15.Piriform R	1.762
19	28.B Point	1.791
20	20.Supradentale	2.182
21	19.A Point	2.212
22	14.Orbitale L	2.711

Overall Aver: 1.438
First Ten Aver: 1.027
Last Ten Aver: 1.865

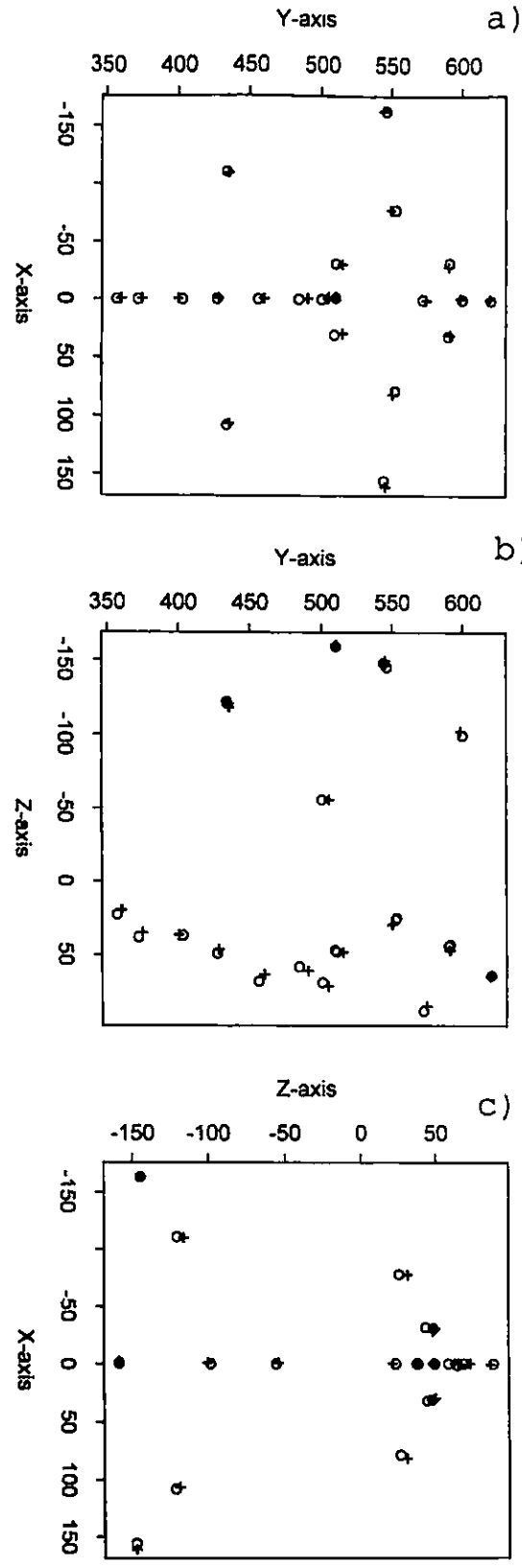


Figure 7. Procrustes Fit of skeletal landmarks comparing Class II for age:6 to age:11 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	21.Upper_Inc_Edge	0.176
2	28.B_Point	0.330
3	25.Infradentale	0.443
4	17.Ant_Nasal_Spine	0.529
5	35.Cen_Inc_RootApR	0.665
6	24.Lower_Inc_Edge	0.745
7	20.Supradentale	0.762
8	36.Cen_Inc_RootApL	0.876
9	19.A_Point	0.920
10	06.Nasion	0.944
11	09.Medial_Orbit_R	0.980
12	18.Pos_Nasal_Spine	0.989
13	10.Medial_Orbit_L	1.109
14	14.Orbitale_L	1.122
15	29.Pogonion	1.182
16	13.Orbitale_R	1.186
17	32.Gonion_L	1.269
18	30.Menton	1.301
19	31.Gonion_R	1.379
20	00.Sella	1.482
21	15.Piriform_R	1.893
22	05.Mech_Porion_L	1.948
23	04.Mech_Porion_R	1.953
24	44.Rhinion	2.034
25	16.Piriform_L	2.074
26	01.Basion	2.397
27	26.Low_1st_Molar_R	3.576
28	27.Low_1st_Molar_L	3.703
29	23.Upp_1st_Molar_L	3.865
30	22.Upp_1st_Molar_R	4.212

Overall Aver: 1.535
First Ten Aver: 0.639
Last Ten Aver: 2.766

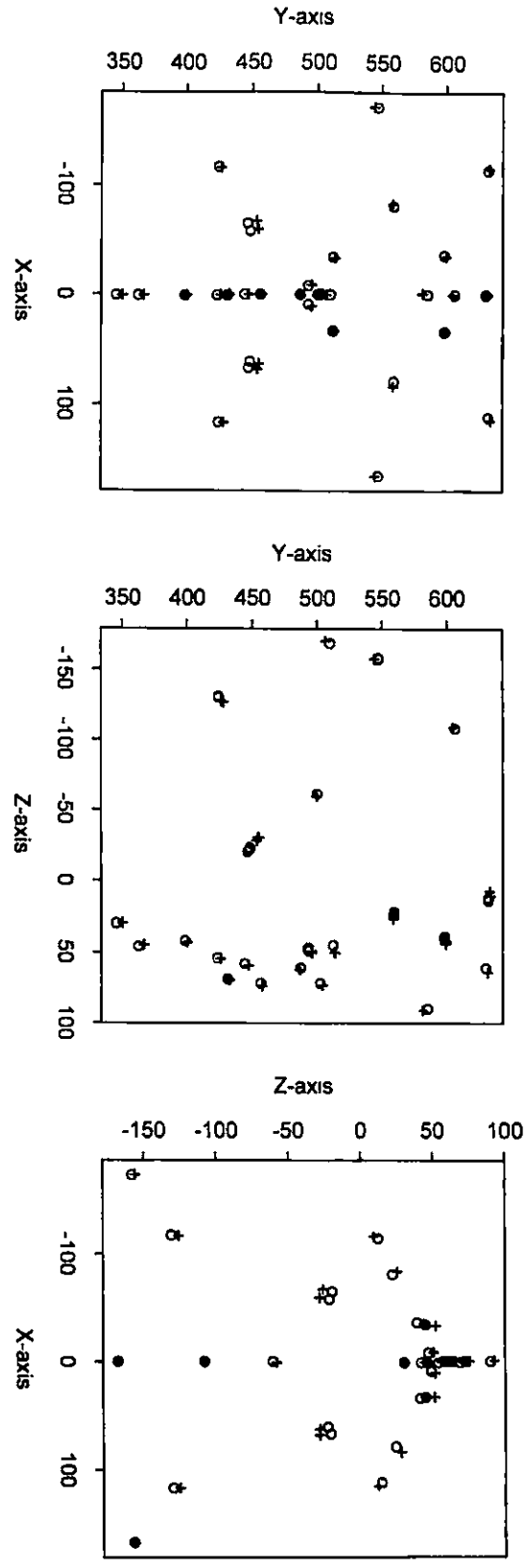


Figure 8. Procrustes Fit of landmarks comparing Class II from age:11 to age:15 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	20.Supradentale	0.142
2	18.Pos Nasal Spine	0.387
3	17.Ant Nasal Spine	0.437
4	28.B Point	0.478
5	19.A Point	0.540
6	14.Orbitale L	0.602
7	13.Orbitale R	0.663
8	09.Medial Orbit R	0.731
9	25.Infradentale	0.745
10	06.Nasion	0.839
11	32.Gonion L	0.921
12	10.Medial Orbit L	0.946
13	00.Sella	1.157
14	05.Mech Porion L	1.226
15	15.Piriform R	1.405
16	31.Gonion R	1.442
17	04.Mech Porion R	1.509
18	16.Piriform L	1.640
19	44.Rhinion	1.790
20	29.Pogonion	1.851
21	30.Menton	1.907
22	01.Basion	2.009

Overall Aver: 1.062
First Ten Aver: 0.556
Last Ten Aver: 1.594

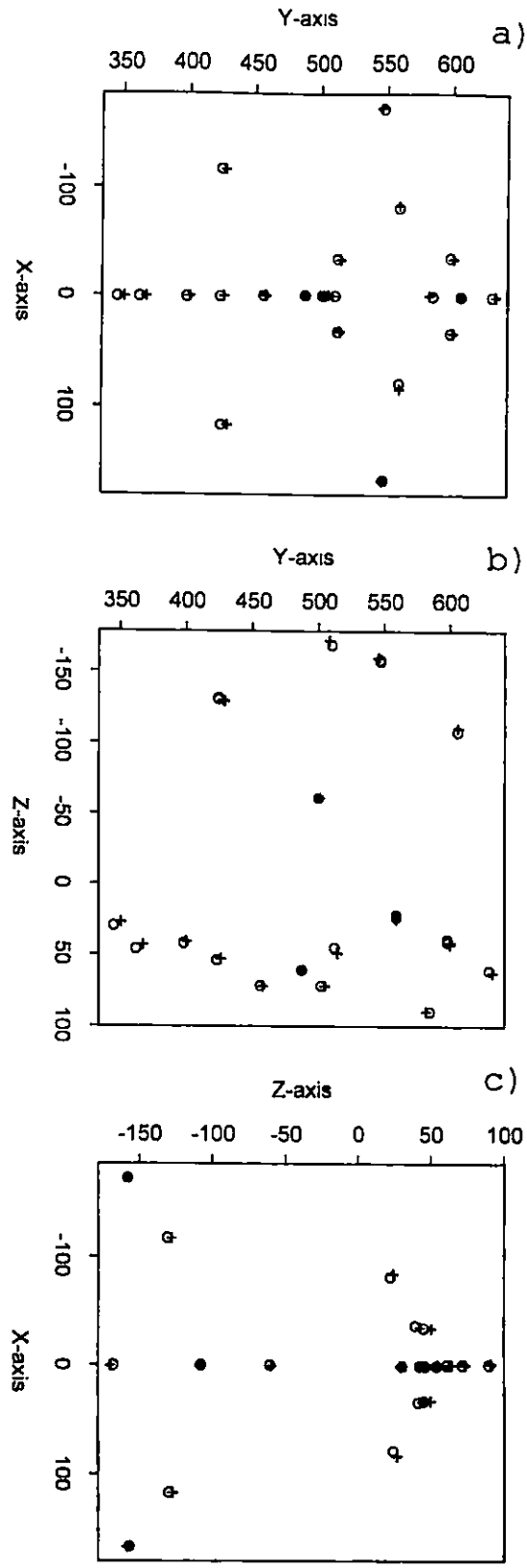


Figure 9. Procrustes Fit of skeletal landmarks comparing Class II for age:11 to age:15 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	18.Pos Nasal Spine	1.102
2	06.Nasion	1.130
3	25.Infradentale	1.591
4	31.Gonion R	1.734
5	28.B Point	1.755
6	17.Ant Nasal Spine	1.840
7	19.A Point	1.861
8	09.Medial Orbit R	1.923
9	44.Rhinion	1.984
10	32.Gonion L	1.998
11	04.Mech Porion R	2.154
12	20.Supradentale	2.228
13	16.Piriform L	2.383
14	10.Medial Orbit L	2.469
15	13.Orbitale R	2.473
16	05.Mech Porion L	2.678
17	15.Piriform R	2.678
18	01.Basion	2.935
19	00.Sella	3.014
20	29.Pogonion	3.133
21	30.Menton	3.322
22	14.Orbitale L	3.480

Overall Aver: 2.267
First Ten Aver: 1.692
Last Ten Aver: 2.857

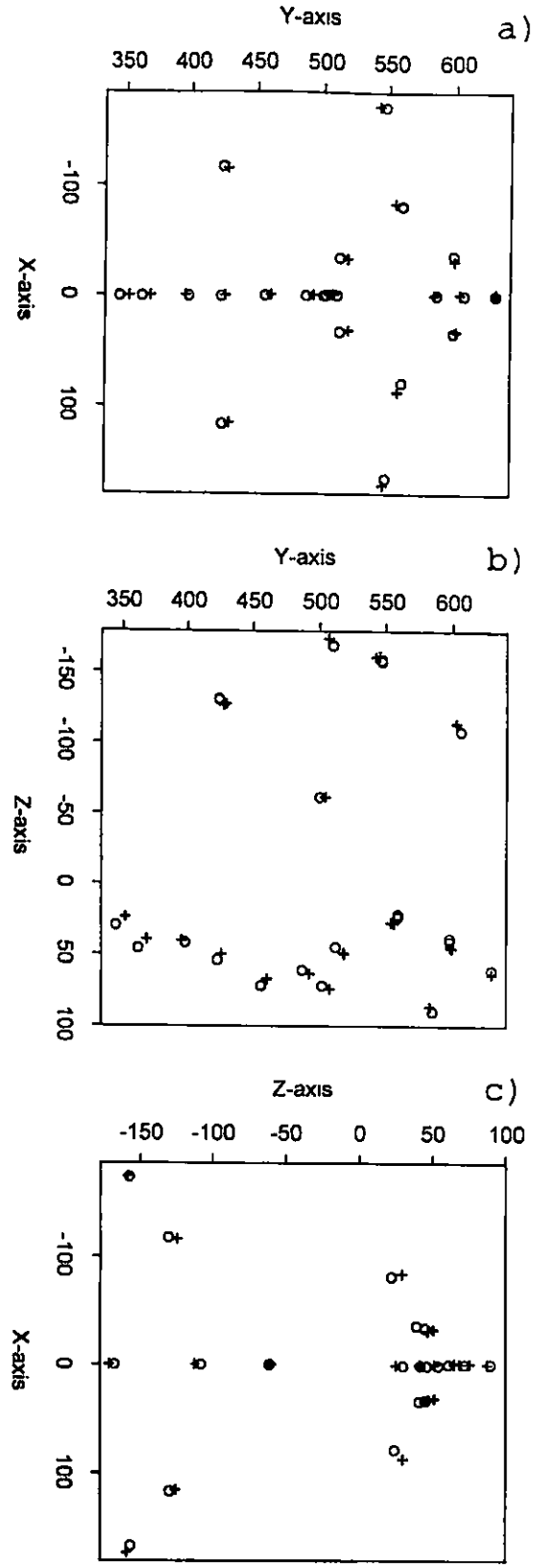


Figure 11. Procrustes Fit of skeletal landmarks comparing Class II for age:6 to age:15 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	06.Nasion	0.054
2	10.Medial_Orbit_L	0.303
3	09.Medial_Orbit_R	0.508
4	32.Gonion_L	0.702
5	28.B_Point	0.716
6	14.Orbitale_L	1.030
7	25.Infradentale	1.032
8	44.Rhinion	1.128
9	31.Gonion_R	1.180
10	18.Pos_Nasal_Spine	1.243
11	13.Orbitale_R	1.248
12	04.Mech_Porion_R	1.353
13	05.Mech_Porion_L	1.692
14	16.Piriform_L	1.747
15	24.Lower_Inc_Edge	1.821
16	20.Supradentale	1.988
17	17.Ant_Nasal_Spine	2.089
18	15.Piriform_R	2.140
19	19.A_Point	2.241
20	29.Pogonion	3.032
21	00.Sella	3.033
22	01.Basion	3.447
23	23.Upp_1st_Molar_L	3.493
24	27.Low_1st_Molar_L	3.619
25	21.Upper_Inc_Edge	3.849
26	30.Menton	3.890
27	22.Upp_1st_Molar_R	3.910
28	26.Low_1st_Molar_R	3.982
29	36.Cen_Inc_RootApL	5.442
30	35.Cen_Inc_RootApR	5.951

Overall Aver: 2.262
First Ten Aver: 0.790
Last Ten Aver: 4.062

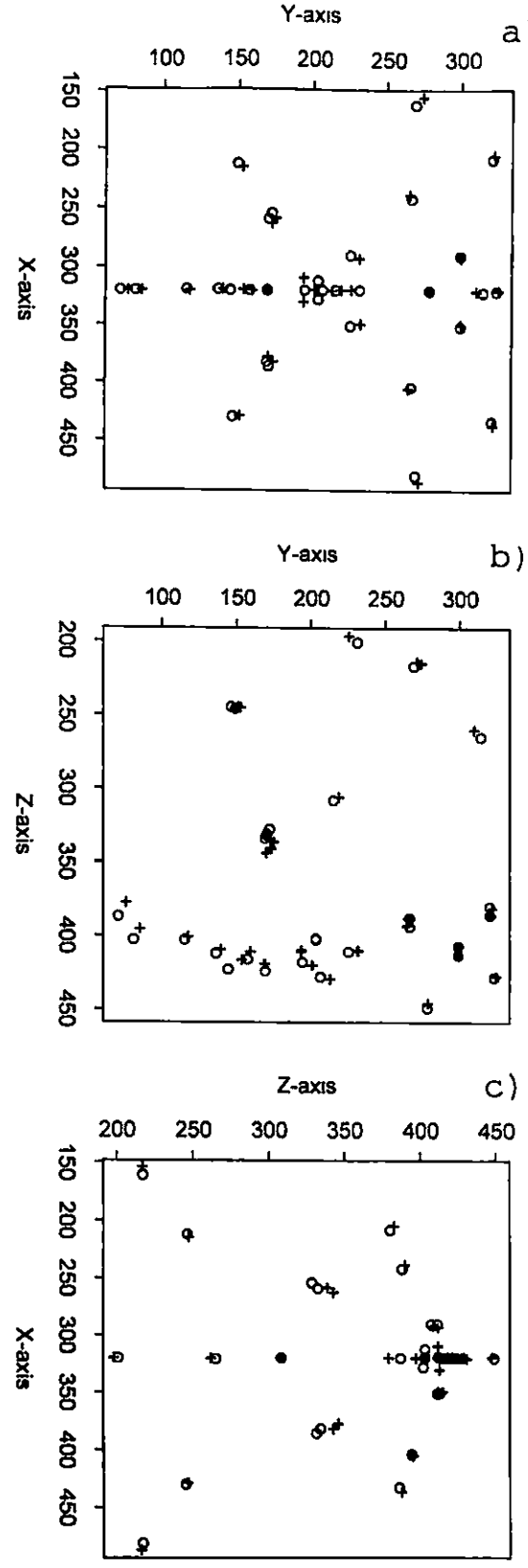


Figure 12. Procrustes Fit of landmarks comparing Class I for age:6 to age:11 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	28.B Point	0.118
2	04.Mech Porion R	0.384
3	25.Infradentale	0.448
4	18.Pos Nasal Spine	0.549
5	06.Nasion	0.620
6	32.Gonion L	0.758
7	44.Rhinion	0.843
8	10.Medial Orbit L	0.937
9	05.Mech Porion L	0.987
10	09.Medial Orbit R	1.179
11	31.Gonion R	1.228
12	20.Supradentale	1.444
13	14.Orbitale L	1.551
14	16.Piriform L	1.597
15	13.Orbitale R	1.628
16	15.Piriform R	1.946
17	29.Pogonion	2.262
18	17.Ant Nasal Spine	2.263
19	19.A Point	2.510
20	00.Sella	2.963
21	30.Menton	3.075
22	01.Basion	3.349

Overall Aver: 1.484
First Ten Aver: 0.682
Last Ten Aver: 2.315

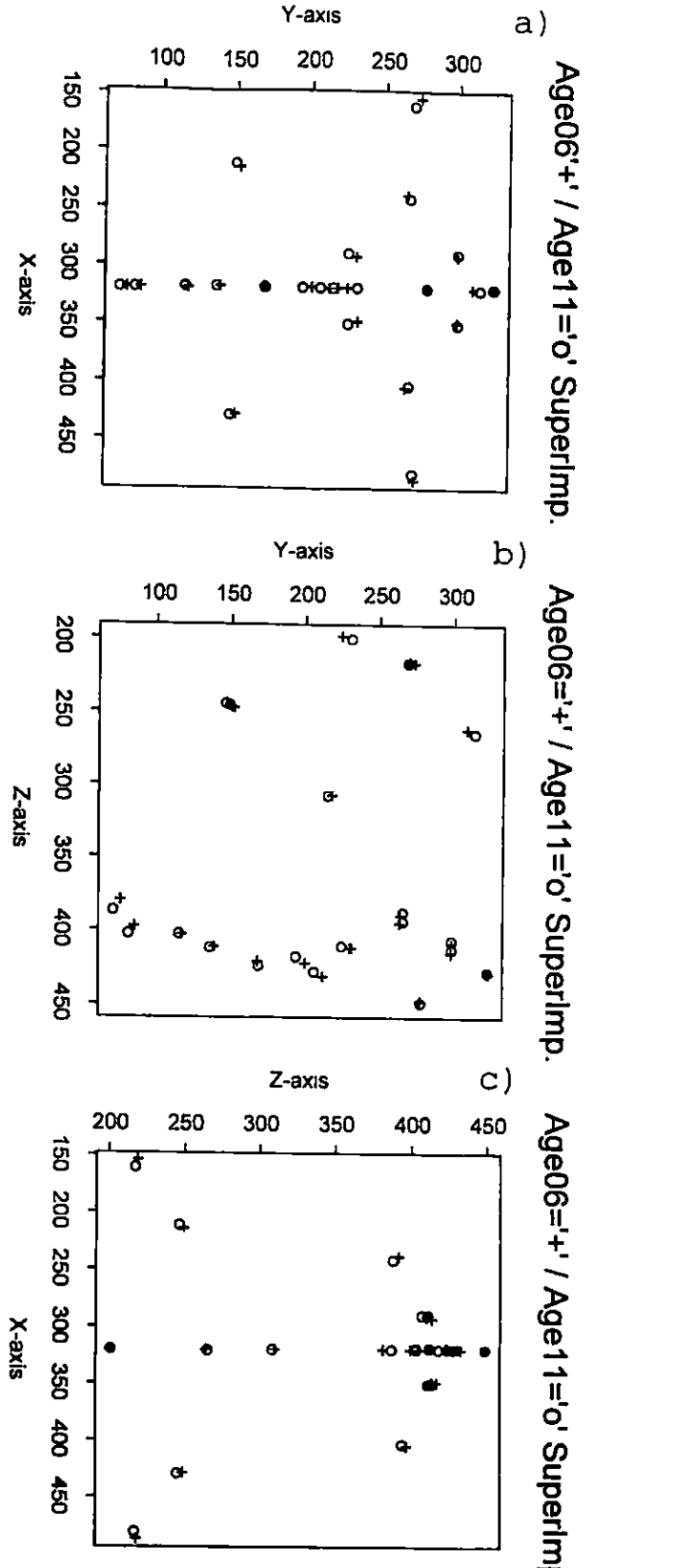


Figure 13. Procrustes Fit of skeletal landmarks comparing Class I for age:6 to age:11 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	25.Infradentale	0.239
2	28.B Point	0.340
3	44.Rhinion	0.407
4	35.Cen Inc RootApR	0.494
5	24.Lower Inc Edge	0.619
6	14.Orbitale L	0.715
7	13.Orbitale R	0.928
8	20.Supradentale	1.003
9	10.Medial Orbit L	1.004
10	15.Piriform R	1.024
11	36.Cen Inc RootApL	1.046
12	17.Ant Nasal Spine	1.058
13	06.Nasion	1.060
14	21.Upper Inc Edge	1.195
15	09.Medial Orbit R	1.206
16	18.Pos Nasal Spine	1.217
17	30.Menton	1.346
18	16.Piriform L	1.397
19	00.Sella	1.440
20	19.A Point	1.526
21	31.Gonion R	1.860
22	04.Mech Porion R	1.889
23	05.Mech Porion L	1.933
24	29.Pogonion	1.944
25	32.Gonion L	2.164
26	01.Basion	2.508
27	22.Upp 1st Molar R	2.873
28	26.Low 1st Molar R	3.137
29	27.Low 1st Molar L	3.306
30	23.Upp 1st Molar L	3.397

Overall Aver: 1.476
First Ten Aver: 0.677
Last Ten Aver: 2.501

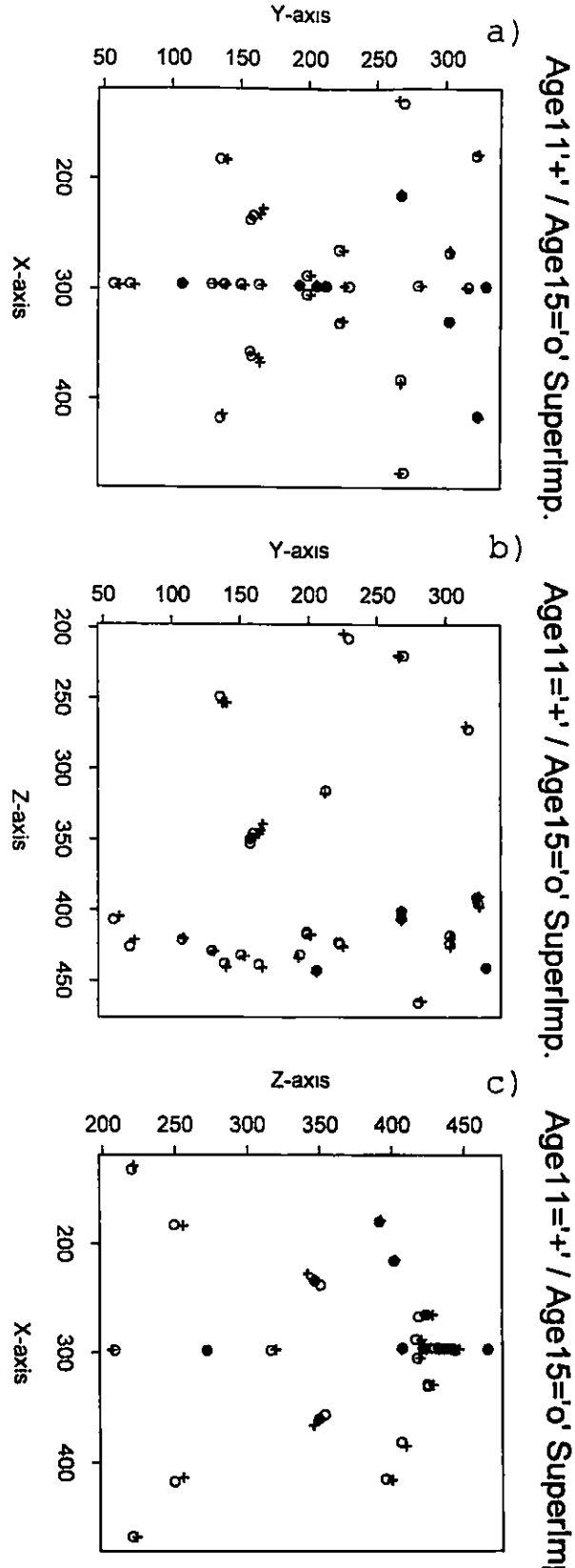


Figure 14. Procrustes Fit of landmarks comparing Class I for age:11 to age:15 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	25.Infradentale	0.193
2	14.Orbitale_L	0.427
3	13.Orbitale_R	0.553
4	18.Pos_Nasal_Spine	0.573
5	28.B_Point	0.628
6	06.Nasion	0.634
7	17.Ant_Nasal_Spine	0.694
8	44.Rhinion	0.695
9	10.Medial_Orbit_L	0.755
10	20.Supradentale	0.856
11	15.Piriform_R	0.971
12	09.Medial_Orbit_R	1.017
13	04.Mech_Porion_R	1.047
14	19.A_Point	1.139
15	00.Sella	1.176
16	05.Mech_Porion_L	1.321
17	31.Gonion_R	1.377
18	16.Piriform_L	1.418
19	30.Menton	1.845
20	32.Gonion_L	2.154
21	01.Basion	2.360
22	29.Pogonion	2.454

Overall Aver: 1.104
First Ten Aver: 0.601
Last Ten Aver: 1.629

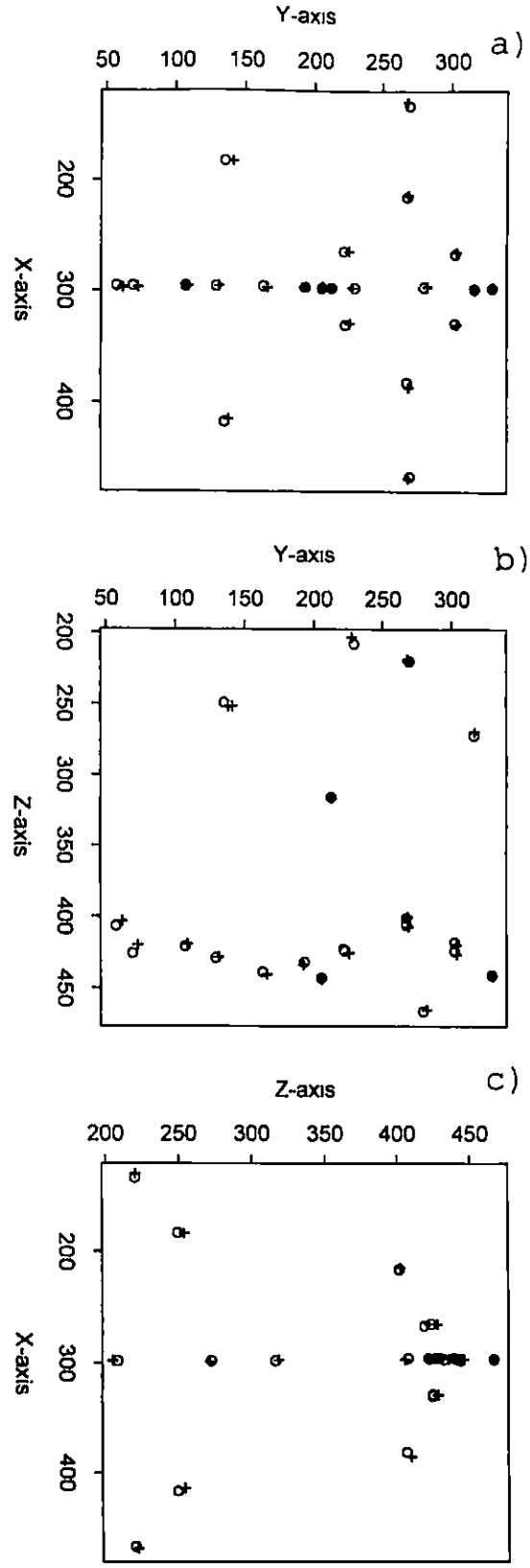


Figure 15. Procrustes Fit of skeletal landmarks comparing Class I for age:11 to age:15 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	18.Pos_Nasal_Spine	0.285
2	25.Infradentale	0.863
3	28.B_Point	0.986
4	06.Nasion	1.044
5	20.Supradentale	1.130
6	05.Mech_Porion_L	1.236
7	10.Medial_Orbit_L	1.287
8	44.Rhinion	1.463
9	24.Lower_Inc_Edge	1.491
10	09.Medial_Orbit_R	1.704
11	14.Orbitale_L	1.756
12	04.Mech_Porion_R	1.782
13	17.Ant_Nasal_Spine	1.885
14	13.Orbitale_R	1.979
15	31.Gonion_R	2.029
16	19.A_Point	2.215
17	26.Low_1st_Molar_R	2.273
18	32.Gonion_L	2.363
19	15.Piriform_R	2.570
20	16.Piriform_L	2.658
21	27.Low_1st_Molar_L	2.915
22	23.Upp_1st_Molar_L	2.946
23	22.Upp_1st_Molar_R	3.176
24	21.Upper_Inc_Edge	3.188
25	00.Sella	4.597
26	29.Pogonion	5.169
27	30.Menton	5.329
28	36.Cen_Inc_RootApL	5.971
29	35.Cen_Inc_RootApR	6.043
30	01.Basion	6.112

Overall Aver: 2.615
First Ten Aver: 1.149
Last Ten Aver: 4.545

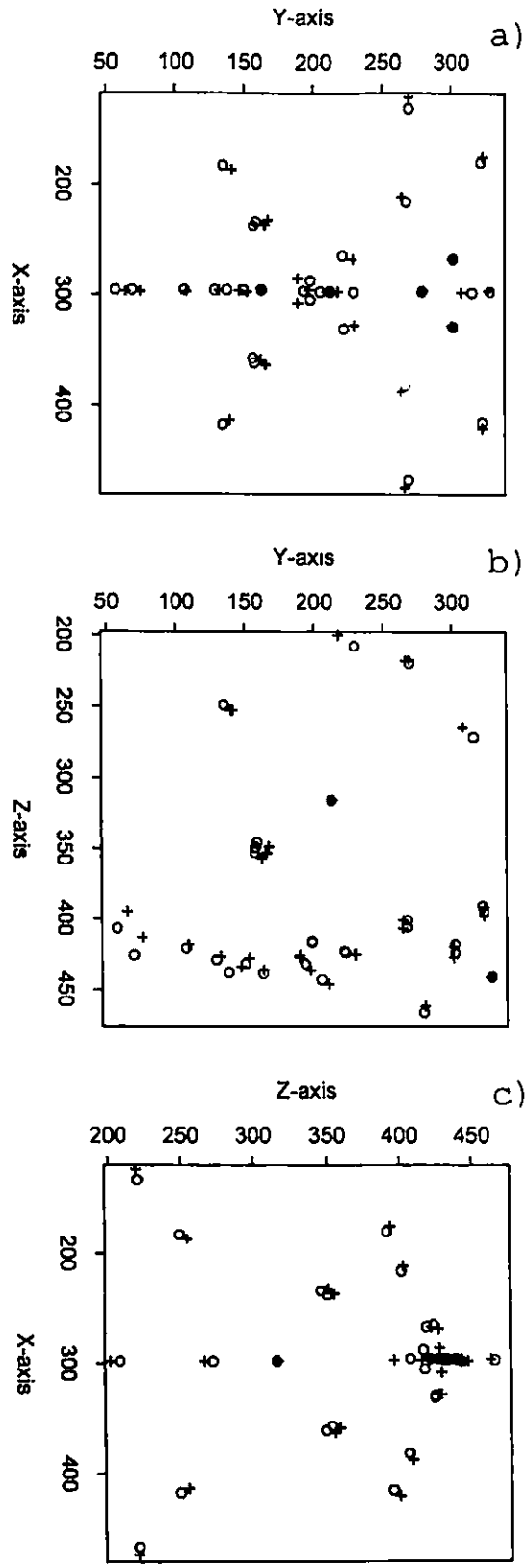


Figure 16. Procrustes Fit of landmarks comparing Class I for age:6 to age:15 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	27.Low 1st Molar L	0.155
2	13.Orbitale R	0.542
3	18.Pos Nasal Spine	0.616
4	24.Lower Inc Edge	0.683
5	21.Upper Inc Edge	0.691
6	22.Upp 1st Molar R	0.823
7	19.A Point	0.917
8	30.Menton	0.972
9	14.Orbitale L	1.388
10	16.Piriform L	1.446
11	29.Pogonion	1.461
12	25.Infradentale	1.678
13	31.Gonion R	1.812
14	10.Medial Orbit L	1.813
15	17.Ant Nasal Spine	1.834
16	15.Piriform R	1.878
17	23.Upp 1st Molar L	1.984
18	09.Medial Orbit R	2.044
19	01.Basion	2.099
20	20.Supradentale	2.117
21	32.Gonion L	2.142
22	26.Low 1st Molar R	2.169
23	00.Sella	2.239
24	35.Cen Inc RootApR	2.666
25	06.Nasion	2.809
26	28.B Point	2.861
27	36.Cen Inc RootApL	3.001
28	44.Rhinion	3.104
29	04.Mech Porion R	3.469
30	05.Mech Porion L	4.569

Overall Aver: 1.866
First Ten Aver: 0.823
Last Ten Aver: 2.903

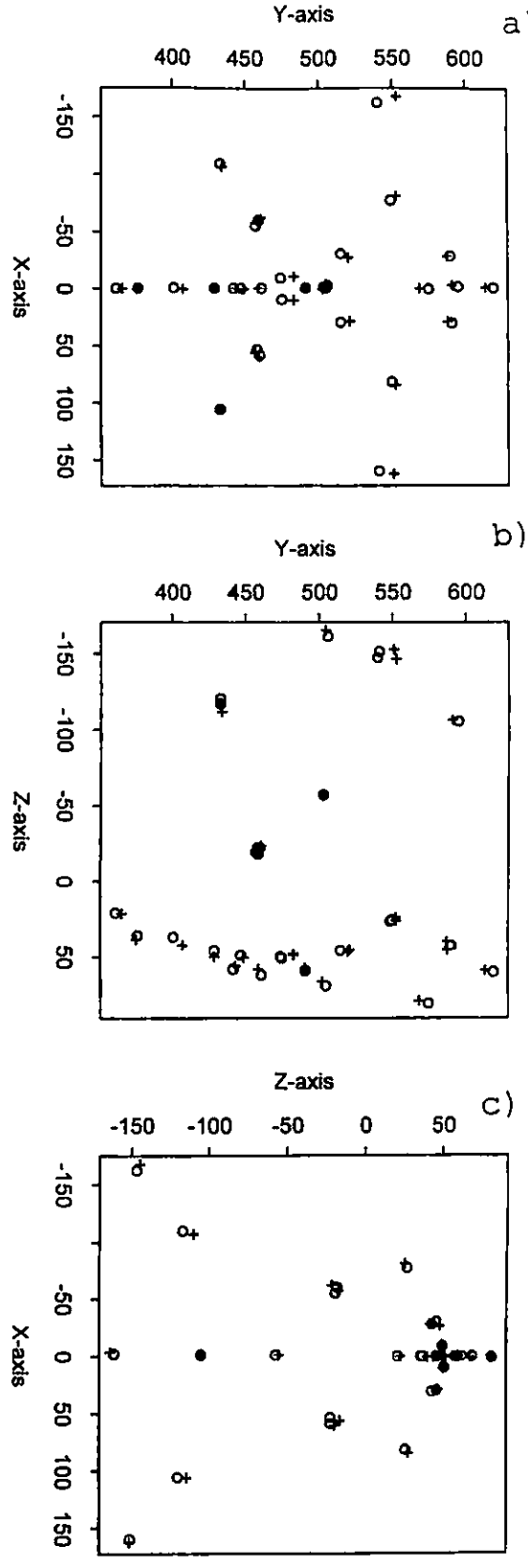


Figure 18. Procrustes Fit of landmarks comparing Class II to Class I for age:6 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	18.Pos Nasal Spine	0.497
2	13.Orbitale R	0.703
3	19.A Point	0.749
4	30.Menton	1.172
5	29.Pogonion	1.425
6	25.Infradentale	1.657
7	17.Ant Nasal Spine	1.663
8	16.Piriform L	1.677
9	14.Orbitale L	1.688
10	10.Medial Orbit L	1.752
11	09.Medial Orbit R	1.784
12	31.Gonion R	1.929
13	20.Supradentale	1.948
14	32.Gonion L	2.047
15	15.Piriform R	2.102
16	01.Basion	2.178
17	00.Sella	2.229
18	06.Nasion	2.581
19	44.Rhinion	2.855
20	28.B Point	3.053
21	04.Mech Porion R	3.391
22	05.Mech Porion L	4.652

Overall Aver: 1.988
First Ten Aver: 1.298
Last Ten Aver: 2.703

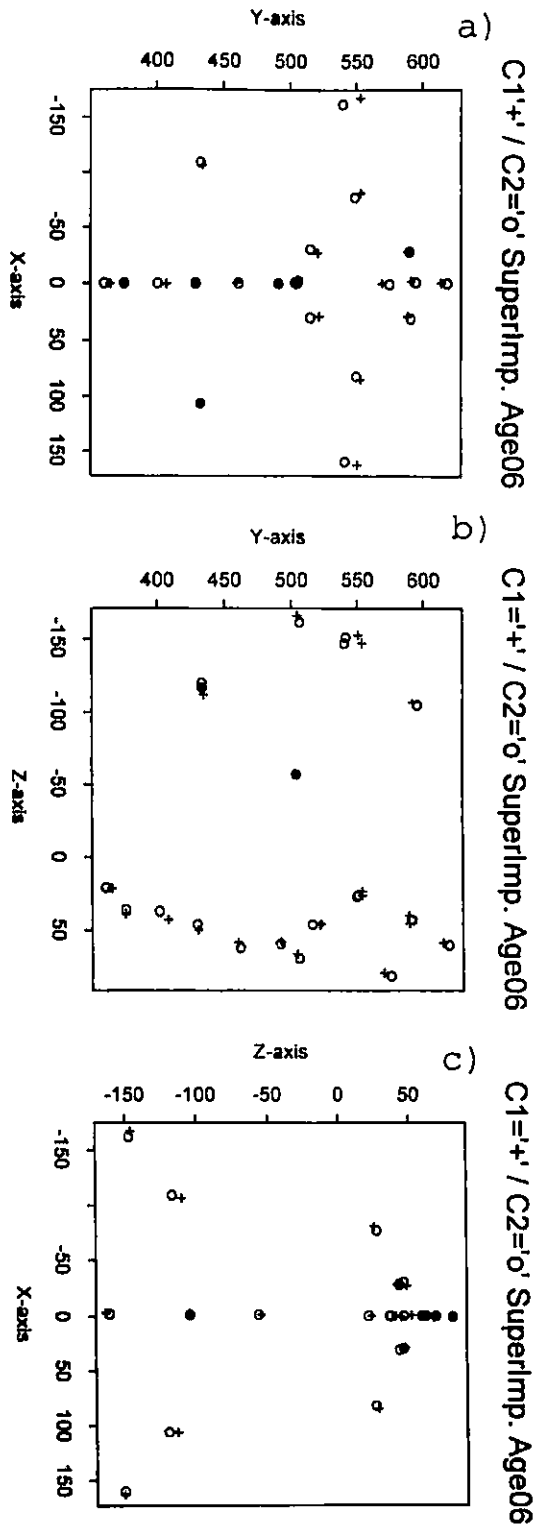


Figure 19. Procrustes Fit of skeletal landmarks comparing Class II to Class I for age:6 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	21.Upper_Inc_Edge	0.244
2	27.Low_1st_Molar_L	0.322
3	14.Orbitale_L	0.410
4	24.Lower_Inc_Edge	0.580
5	18.Pos_Nasal_Spine	0.587
6	22.Upp_1st_Molar_R	0.603
7	26.Low_1st_Molar_R	0.858
8	00.Sella	0.891
9	19.A_Point	0.909
10	10.Medial_Orbit_L	1.336
11	25.Infradentale	1.371
12	13.Orbitale_R	1.488
13	16.Piriform_L	1.530
14	09.Medial_Orbit_R	1.550
15	01.Basion	1.984
16	15.Piriform_R	2.004
17	44.Rhinion	2.116
18	36.Cen_Inc_RootApL	2.168
19	05.Mech_Porion_L	2.287
20	17.Ant_Nasal_Spine	2.301
21	20.Supradentale	2.308
22	30.Menton	2.363
23	23.Upp_1st_Molar_L	2.392
24	31.Gonion_R	2.404
25	28.B_Point	2.518
26	29.Pogonion	2.695
27	35.Cen_Inc_RootApR	3.036
28	06.Nasion	3.101
29	32.Gonion_L	3.105
30	04.Mech_Porion_R	3.523

Overall Aver: 1.766
First Ten Aver: 0.674
Last Ten Aver: 2.744

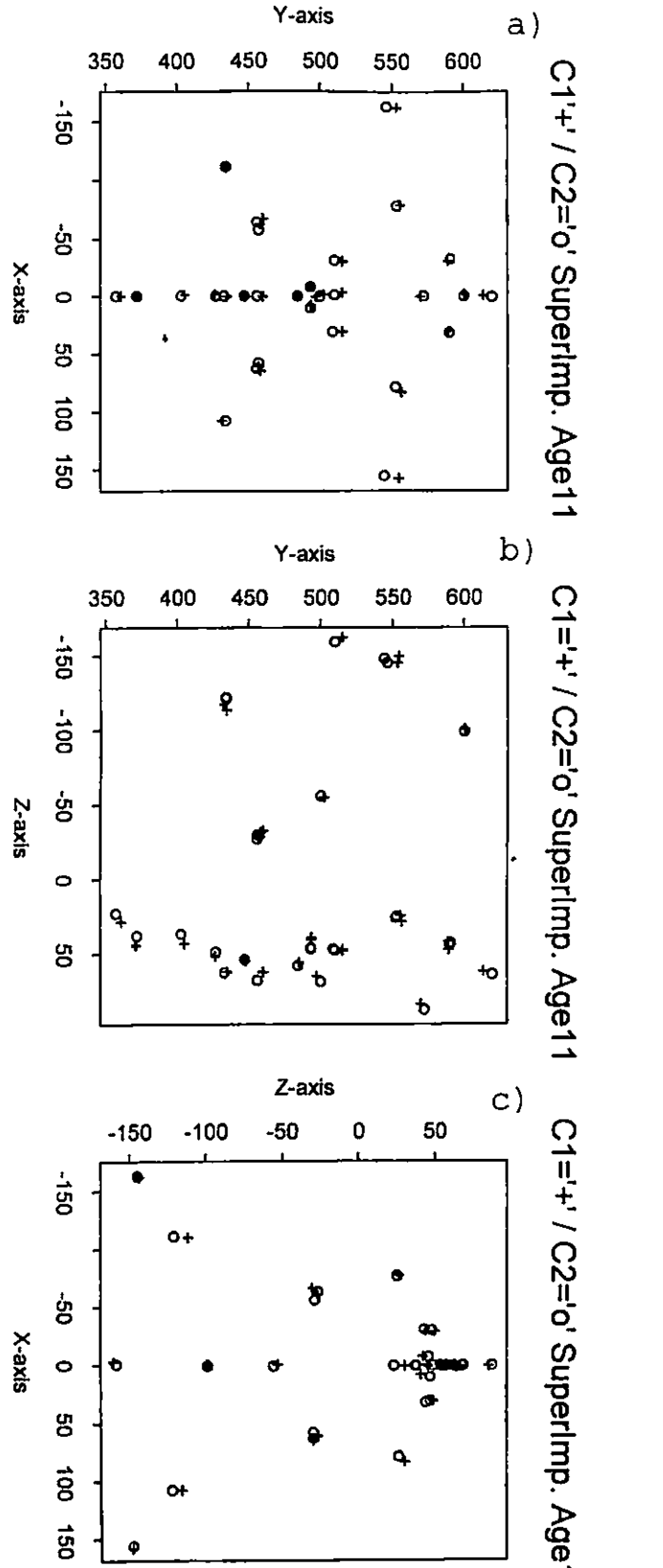


Figure 20. Procrustes Fit of landmarks comparing Class II to Class I for age:11 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	18.Pos Nasal Spine	0.355
2	14.Orbitale L	0.522
3	00.Sella	1.087
4	25.Infradentale	1.223
5	19.A Point	1.228
6	13.Orbitale R	1.277
7	09.Medial Orbit R	1.417
8	10.Medial Orbit L	1.447
9	16.Piriform L	1.450
10	15.Piriform R	1.889
11	30.Menton	1.928
12	28.B Point	2.138
13	31.Gonion R	2.163
14	01.Basion	2.304
15	44.Rhinion	2.337
16	29.Pogonion	2.394
17	05.Mech Porion L	2.492
18	20.Supradentale	2.566
19	17.Ant Nasal Spine	2.566
20	32.Gonion L	2.634
21	06.Nasion	3.210
22	04.Mech Porion R	3.597

Overall Aver: 1.919
First Ten Aver: 1.190
Last Ten Aver: 2.626

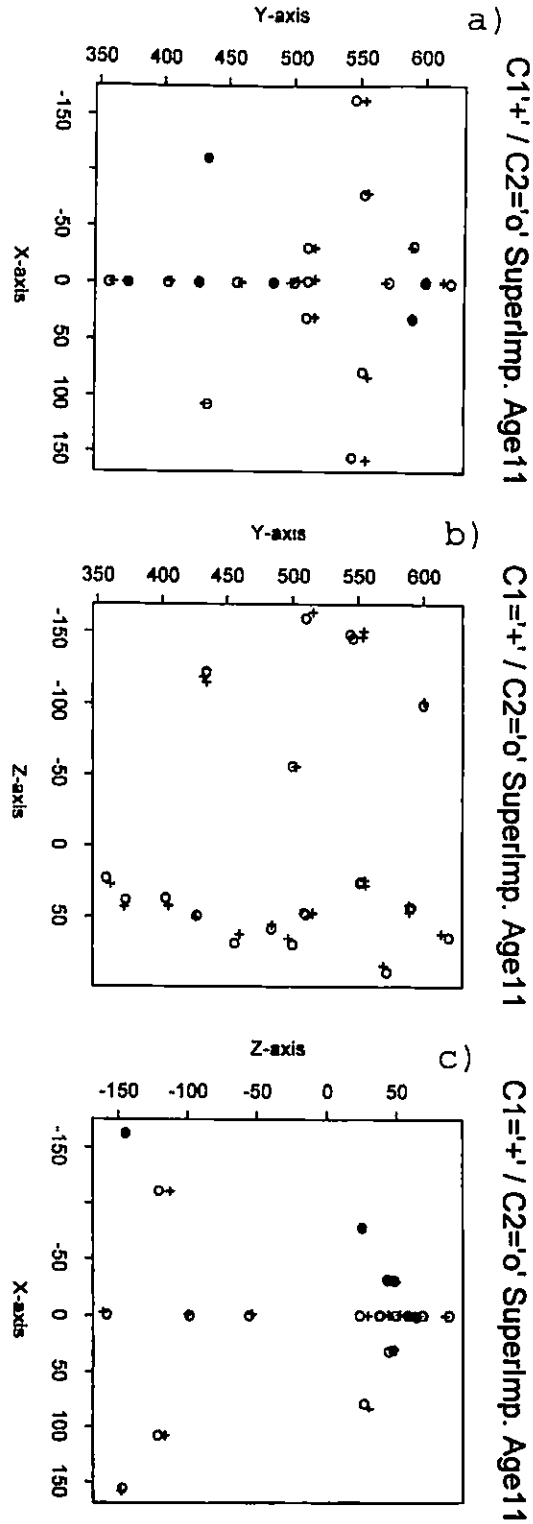


Figure 21. Procrustes Fit of skeletal landmarks comparing Class II to Class I for age:11 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	18.Pos Nasal Spine	0.439
2	26.Low 1st Molar R	0.550
3	24.Lower Inc Edge	0.554
4	10.Medial Orbit L	0.766
5	14.Orbitale L	0.768
6	27.Low 1st Molar L	0.844
7	00.Sella	0.922
8	25.Infradentale	1.288
9	21.Upper Inc Edge	1.309
10	16.Piriform L	1.370
11	09.Medial Orbit R	1.387
12	19.A Point	1.462
13	13.Orbitale R	1.476
14	31.Gonion R	1.694
15	01.Basion	1.808
16	15.Piriform R	1.930
17	17.Ant Nasal Spine	1.932
18	22.Upp 1st Molar R	2.017
19	06.Nasion	2.154
20	05.Mech Porion L	2.458
21	36.Cen Inc RootApL	2.496
22	20.Supradental	2.533
23	35.Cen Inc RootApR	2.932
24	23.Upp 1st Molar L	3.088
25	28.B Point	3.195
26	30.Menton	3.384
27	32.Gonion L	3.411
28	44.Rhinion	4.019
29	04.Mech Porion R	4.204
30	29.Pogonion	4.227

Overall Aver: 2.021
First Ten Aver: 0.881
Last Ten Aver: 3.349

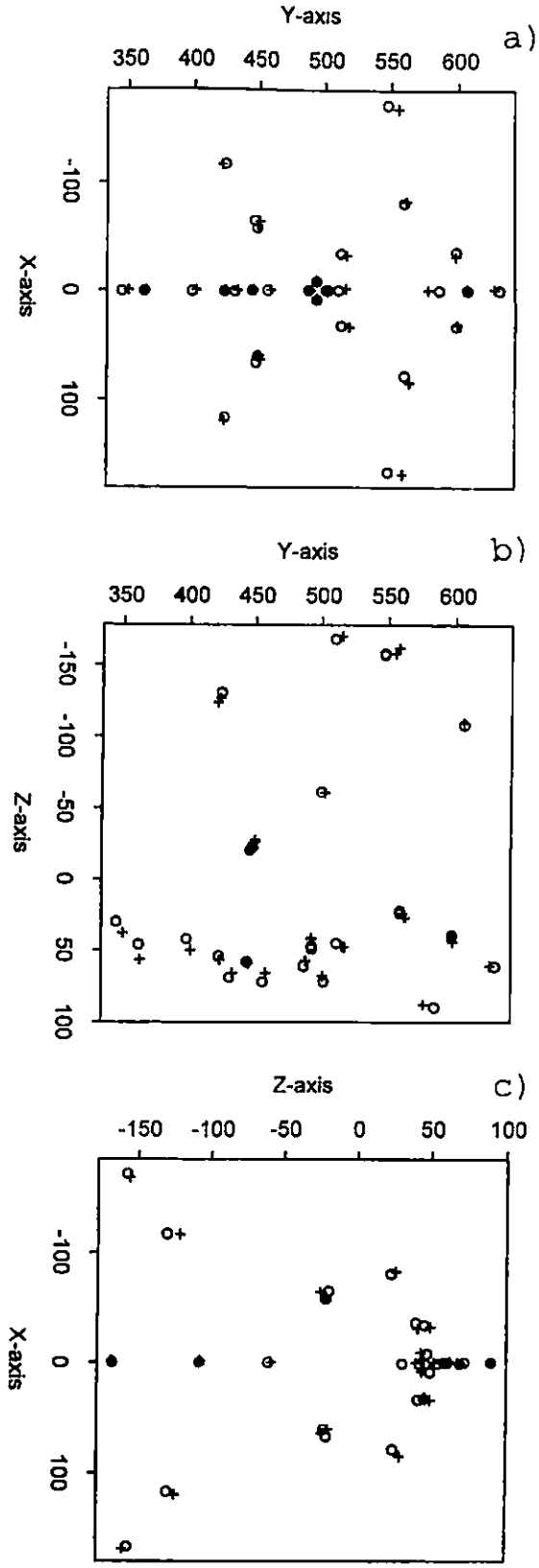


Figure 22. Procrustes Fit of landmarks comparing Class II to Class I for age:15 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

Rank	Labels	PDU
1	14.Orbitale_L	0.281
2	18.Pos_Nasal_Spine	0.587
3	25.Infradentale	0.741
4	16.Piriform_L	0.942
5	10.Medial_Orbit_L	1.029
6	13.Orbitale_R	1.060
7	00.Sella	1.088
8	09.Medial_Orbit_R	1.157
9	31.Gonion_R	1.255
10	15.Piriform_R	1.555
11	19.A_Point	2.048
12	01.Basion	2.194
13	06.Nasion	2.446
14	28.B_Point	2.484
15	17.Ant_Nasal_Spine	2.499
16	30.Menton	2.675
17	32.Gonion_L	2.737
18	05.Mech_Porion_L	2.771
19	20.Supradentale	3.153
20	29.Pogonion	3.455
21	04.Mech_Porion_R	4.345
22	44.Rhinion	4.375

Overall Aver: 2.040
First Ten Aver: 0.970
Last Ten Aver: 3.094

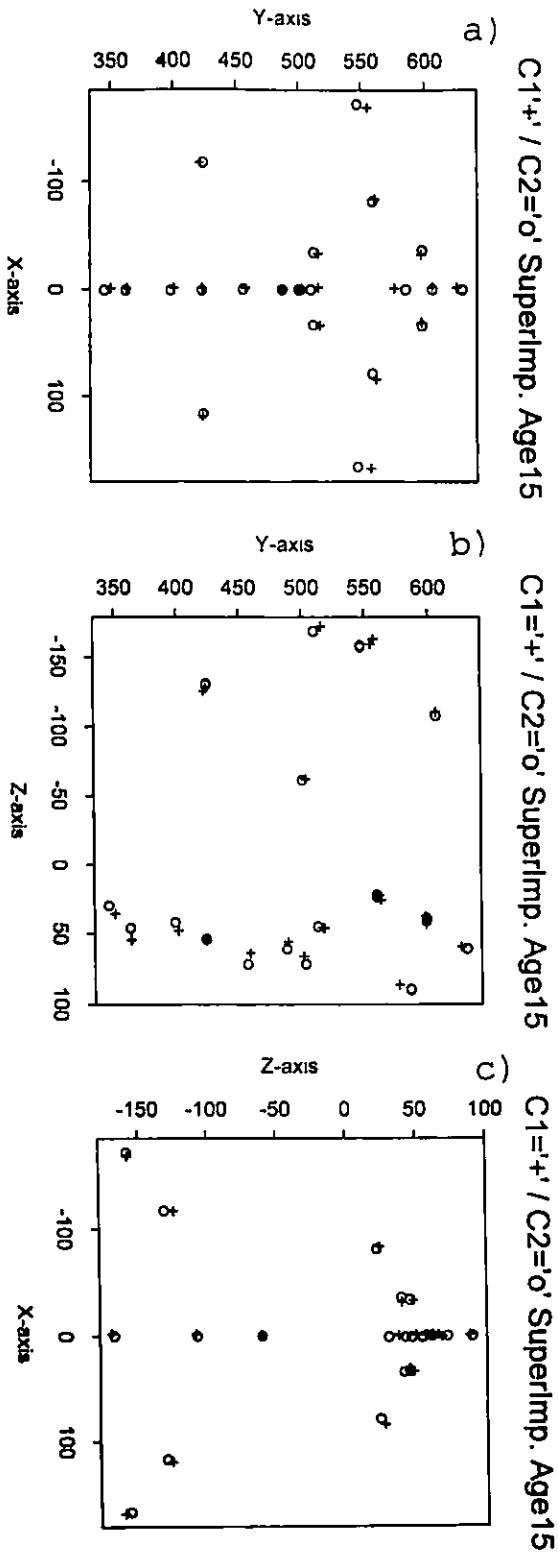


Figure 23. Procrustes Fit of skeletal landmarks comparing Class II to Class I for age:15 in a) frontal view, b) lateral view, and c) axial view. Each landmark is ranked in ascendant order for shape modification.

GLOSSARY

The landmarks and correspondent definitions used in this study are presented here in alphabetical order:

1. **A Point:** Most posterior point in the lateral view along the line between the anterior nasal spine and the alveolar crest of the upper central incisor.

2. **Antegonial Notch** (bilateral): The point of maximum curvature that is the greatest depth of incurvation. The notch is found between the posterior third and anterior two thirds of the inferior mandibular border (i.e., between the ramus and corpus). It is not necessarily the highest point in Frankfort horizon.

3. **Anterior Nasal Spine:** Sharp process, which is a prolongation of the superior-anterior-most parts of medial junction between both maxillae. It is most apparent in the lateral view and is obvious when sighing across to the midline of the frontal view.

4. **B Point:** Most posterior point in the lateral view along the ling between the alveolar crest of the lower central incisor and pogonion.

5. **Basion:** Point where the median sagittal plane of the skull intersects the lowest point on the anterior margin of the foramen magnum.

6. **Central Incisor Root Apex** (bilateral): Recognized in the lateral view. It is the intersection of the superior poles of the

roots of the upper central incisor roots. Not apparent in children under six years of age. The top of the deciduous incisor root is used in children 2-6 years old. Broadbent Orientator alignment to midline for frontal view.

7. **Condylion** (bilateral): The most superior point on the superior curvature of the condyle. This point is usually difficult to view in the lateral view. There is often the need to estimate the right and left landmarks based on nearby structures. It may be easier to begin with the frontal view and sighted across the Orientator to the lateral view. Assuming the head position is correct and there is no significant right-left asymmetry, the right condylion is located more anteriorly than left condylion.

8. **Endinion:** Most anteriorly projecting point at the confluence of sinuses. The point is easily located at the inferior terminus of the superior sagittal sinus and the posterior terminus of the tentorium and beginning of the transverse sinus.

9. **Euryon** (bilateral): The most prominent lateral point on each side of the skull in the area of the parietal and occipital bones.

10. **Glabella:** The most anterior point on the midline of the brow.

11. **Gonion** (bilateral): The external angle of the mandible, located on the lateral radiograph by bisecting the angle formed by tangent of the posterior border of the ramus and the inferior border of the mandibular corpus (i.e., a line passing under the inferior border below menton to the posterior to gonion). This can be located with a protractor, although future versions of 3dCEPH will have an on-screen tool to

find this point. Note: when this point is sighted across it to the frontal image it will usually not correspond to the widest point in the gonial region. However, the intersection with the sighting line should be taken as gonion in the frontal view. Assuming the head position is correct and that there is no significant asymmetry, the right gonion point is located more anteriorly and inferiorly. The vertical height of this point can be checked on the frontal cephalogram, although note that is not the widest point in most cases.

12. **Infradentale:** The superior-most point of the alveolar bone between both central upper incisors.

13. **Inion:** External occipital protuberance. Superior-most attachment point for nuchal ligament. Defines border between scalp and neck muscles. Can be elongate in adult males.

14. **Lateral Condylar Pole** (bilateral): This point is seeing in the frontal view as most lateral tip of the condylar head. In the lateral view trace the anterior and posterior condylar borders superiorly. Sight across the Broadbent Orientator to an intersection with the posterior border of the mandible. The landmark is at the midpoint of the line connecting this point to a horizontal intersecting the anterior condylar borderline (aka. MGH point).

15. **Lateral Orbit Point** (bilateral): The superolateral-most point on the orbital outline, roughly corresponding to the frontozygomatic suture. Assuming the head position is correct and that there is no significant asymmetry, the right lateral orbit point is located more superiorly and anteriorly.

16. **Lower First Molar Cusp** (Bilateral): The distobuccal cusp tip of the lower first molar. Often superimposing the Bolton Standards templates on the molar teeth helps in recognition of this point. Assuming the head position is correct and there is no significant asymmetry in the dentition, the right first molar cusp is located more anteriorly and inferiorly than the left first molar cusp.

17. **Lower Incisor Edge**: Recognized in the lateral view. The intersection of the superior tips of the central lower incisor crowns. Broadbent Orientator alignment to midline for frontal view.

18. **Mastoidale** (bilateral): The lowest point on the contour of the mastoid process.

19. **Mechanical Porion** (bilateral): Founded by using Broadbent template. After placing the ear rod template in position on the lateral films, the center of the ring forms an axis of rotation if any rotation is necessary to get of the frontal and lateral views. Mechanical Porion is at the top of this ring, which is the closest to the film. The right and left mechanical Porion are located in the frontal view by tracing the centerline of the ear rod to its intersection with the bony external auditory meatus (on the temporal bone, not the skin).

20. **Medial Orbit Point** (bilateral): Located in the frontal view first and sighted across to the lateral image. The top of the lacrimal crest (lacrimale), anterior to nasolacrimal duct. There is often a small crest posterior to this duct. In most cases the paranasal sinuses and ethmoid sinuses will produce two small spaces medial to the lucency within the nasolacrimal duct. When viewed on a dry skull, this point is the medial termination of the inferior orbital

crest on the lacrimal bone or the frontal process of the maxilla in cases where the lacrimal bone does not surround the duct. Assuming the head position is correct and that there is no significant asymmetry, the right medial orbital point is located more superiorly and anteriorly.

21. **Menton:** The most inferior point on the symphysis of the mandible in the median plane. Seen in the lateral radiograph as the most inferior point on the symphysial outline when the head is oriented to Frankfort horizon.

22. **Nasion:** On the lateral film find most posterior point on the arc between glabella and rhinion, roughly approximating the nasofrontal suture. Use the Broadbent Orientator to find this point's intersection with the midline.

23. **Opisthion:** Point where the median sagittal plane of the skull intersects the lowest point on the posterior margin of the foramen magnum.

24. **Opisthocranion:** Most posterior point on the external surface of the occipital bone. Usually between obelion (can be cut off) and inion. Usually slightly above lambda (not discernable on plain film x-ray).

25. **Orbitale** (bilateral): The most inferior point on the inferior orbital rim in the lateral view. It is used in conjunction with the Porion to determine the Frankfort horizontal. Assuming the head position is correct and that there is no significant asymmetry, the right orbitale point is located more anteriorly.

26. **Piriform** (bilateral): In the frontal view it is the widest point in the aperture. Note that the borders of the nasal cavity

are much more radiopaque than the piriform aperture line, which is often faint. It is, roughly, the posterior point on the lateral view of the nasal aperture line; however, the Broadbent Orientator can help in selecting this point.

27. **Pogonion:** The most anterior point on the symphysis of the mandible seen in the lateral view when the head is oriented to Frankfort horizon.

28. **Posterior Nasal Spine:** Process formed at the posteromedial ends of the posterior borders of the two palatine bones (hard palate). This point corresponds to a point at the intersection of a tangent line representing the pterygomaxillary fissure and the horizontal plane of the hard palate.

29. **Rhinion:** The tip of the bony nose. It is the anterior-most external point on the internasal suture.

30. **Sella:** Hypophyseal, or pituitary, fossa or sphenoid bone lodging the pituitary body. The observer makes a best guess of the center point of the pituitary fossa, as seen in the lateral radiograph and located by inspection.

31. **Supradentale:** The inferior-most point of the alveolar bone between both upper central incisors.

32. **Supraorbital Point** (bilateral): The most superior point of the supraorbital line. Roughly corresponds to the lateral border of the supraorbital notch. Assuming the head position is correct and there is no significant asymmetry, the right supraorbital point is located more superiorly and anteriorly. The frontal image can be used to confirm the height of this point.

33. **Upper First Molar Cusp** (bilateral): The distobuccal cusp tip of the upper first molar. Often superimposing the Bolton Standards templates on the molar teeth here helps in recognition of this point. Note that this is a departure from the traditional cephalometric use of the mesiobuccal cusp of the first molar. The mesiobuccal cusp's location is more difficult to estimate in three dimensional plain film x-ray cephalometrics. Assuming the head position is correct and there is no significant asymmetry in the dentition, the right first molar cusp is located more anteriorly and inferiorly than the left first molar cusp.

34. **Upper Incisor Edge:** Recognized in the lateral view. The intersection of the inferior tips of the upper central incisors crowns. Broadbent Orientator alignment to midline for frontal view.

35. **Vertex:** The highest point of the head when the head is orientated in the Frankfort Horizontal plane. The bony landmark in the middle of the top of the skull, where the coronal and sagittal sutures cross.

BIBLIOGRAPHY

Adenwalla, ST, Kronman, JH, and Attarzadeh, F. 1988. Porion and condyle as Cephalometric landmarks - an error study. Am J Orthod Dentofacial Orthop 94(5):411-415.

Altemus, LA. 1959. Frequency of the incidence of malocclusion in American Negro children aged twelve to sixteen. Angle Orthod (24):189-200.

Altobelli, DE, Kikinis, R, Mulliken, JB, Cline, H, Lorensen, W, and Jolesz, F. 1993. Computer assisted three-dimensional planning in craniofacial surgery. Plast Reconstr Surg 92(4):576-585.

Ast, DB, Carlos, JP, Cons, DC. 1965. Prevalence and characteristics of malocclusion among senior high school students in up-state New York. Am J Orthod 1965(51):437-445.

Bailey, J. 1992. The long view of health. Cleveland, OH. Case Western Reserve University. 4(2):26-31.

Baumrind, S and Frantz, R. 1971. The reliability of head film measurements. Am J Orthod Dentofacial Orthop 60(2):111-127.

Baumrind, S, Moffit, F and Curry, S. 1983. Three-dimension x-ray stereometry from paired coplanar images: a progress report. Am J Orthod Dentofacial Orthop 84:292-312.

Baumrind, S, Moffit, F and Curry, S. 1983. The geometry of three dimensional measurements from paired coplanar x-ray images: a progress report. Am J Orthod Dentofacial Orthop 84:313-322.

Bettega, G and Chenin, M. 1996. Three dimensional fetal cephalometry. Cleft Palate Craniofac J 33(6):463-467.

Binder, RE. 1979. The geometry of cephalometrics. J Clin Orthod 13(4):258-264.

Bishara, SE, Jamison, JE, Peterson, LC, and DeKock, WH. 1981. Longitudinal changes in standing height and mandibular parameters between the ages of 8 and 17 years. Am J Orthod (80):115-135.

Bishara, SE, Peterson, LC, and Bishara, EC. 1984. Changes in facial dimensions and relationships between the ages of 5 and 25 years. Am J Orthod Dentofacial Orthop 85(3):238-252.

Bishara, SE, Bayati, P, and Jakobsen, JR. 1996. Longitudinal comparisons of dental arch changes in normal and untreated Class II, Division I subjects and their clinical implications. Am J Orthod Dentofacial Orthop 110(5):483-489.

Bishara, SE, Jakobsen, JR, Vorhies, B, and Bayati, P. 1997. Changes in dentofacial structures in untreated Class II, Division I and normal subjects: A longitudinal study. Angle Orthod 67(1):55-66.

Bishara, SE. 1998. Mandibular changes in persons with untreated and treated Class II, Division I malocclusion. Am J Orthod Dentofacial Orthop 113(6):661-73.

Blafer, JL. 1971. The new cephalometrics: the Musj fronto-facial analysis. J Clin Orthod 5(2):84-100.

Bookstein, FL. 1983. The geometry of craniofacial growth invariants. Am J Orthod Dentofacial Orthop 83(3): 221-234.

Broadbent, BH. 1931. A new x-ray technique and its application to orthodontia. Angle Orthod 1:45-69.

Broadbent, BH, Broadbent Jr., BH and Golden, W. 1975. Bolton Standards of Dentofacial Developmental Growth. St. Louis. Mosby. 1-78.

Brown, T. 1970. Skeletal maturity and facial growth assessment. Aust Orthod J (2):80-87.

Buschang, PH, Tanguay, R, Demirjian, A, LaPalme, L, and Turkewicz, J. 1986. A Polynomial approach to Craniofacial growth: Description and comparison of adolescent males with normal occlusion and those with untreated Class II malocclusion. Am J Orthod Dentofacial Orthop 90(1986):437-442.

Buschang, PH, Tanguay, R, Demirjian, A, LaPalme, L, and Turkewicz, J. 1988. Mathematical models of longitudinal mandibular growth for children with normal and untreated Class II, division 1 malocclusion. Eur Orthod 10(1988):227-234.

Craig, EC. 1951. The skeletal patterns and characteristic of Class I and Class II, Division I malocclusions in norma lateralis. Angle Orthod 1951(21):44-56.

Dean, D, Subramanyan, K, and Kim, E. 1997. New 3D Bolton Standards: co-registraition of biplane x-rays and 3D CT. SPIE 3034:541-549.

Drelich, RC. 1948. A cephalometric study of untreated Class II Division I malocclusion. Angle Orthod 1948(18):70-75.

Enlow, DH, and Harris, D. 1964. A study of the postnatal growth of the human mandible. Am J Orthod Dentofacial Orthop 50(1):25-50.

Fisk, GV, Culbert, MR, Grainger, RM, Hemrend, B, and Moyers, R. 1953. The morphology and physiology of distocclusion. Am J Orthod 1953(35):3-12.

Goldberg, M. 1973. Cephalometrics. Int J Orthod 11(4): 111-129.

Goldstein, MS, Stanton, FL. 1936. Various types of occlusion and amounts of overbite in normal and abnormal occlusion between two and twelve years. Int J Orthod 1936(22):549-569.

Graber, T.M.: 1969. Current Orthodontic Concepts and Techniques. Philadelphia, W.B.Saunders Co., 227.

Gravely, JF, and Benzies, PM. 1974. The clinical significance of tracing error in cephalometry. Br J Orthod 1(3):95-101.

Grayson, BH, Cutting, FL, Bookstein, FL, Kim, H, and McCarthy, JG. 1988. The three dimensional cephalogram: theory, technique and clinical application. Am J Orthod Dentofacial Orthop 94: 237-337.

Greulich, WW, and Pyle, SI. 1959. Radiographic atlas of skeletal development of the hand and wrist. Palo Alto, CA.: Stanford University Press.

Hans, MG, Broadbent Jr., BH, and Nelson, S. 1994. The Broadbent-Bolton Growth Study: past, present and future. Am J Orthod Dentofacial Orthop 105:598-603.

Hillesund, E, Fjeld, D, and Zachrisson, Bu. 1978. Reliability of soft-tissue profile in cephalometrics. Am J Ortho 74(5):537-550.

Hixon, EH. 1972. Cephalometrics: A perspective. Angle Orthod 42(3):200-211.

Lewis, AB, Roche, AF, and Wagner, B. 1985. Pubertal spurt in cranial base and mandible: Comparisons within individuals. Angle Orthod 55:17-30.

Liebgott, B. 1978. Dental age: its relation to skeletal age and the time of peak circumpubertal growth in length of the mandible. Dent J 44(5):223-227.

Maganzini, A. 1974. Developmental history of cephalometrics: A review. Int J Orthod 12(1):5-24.

Maj, G., Luzi, C, and Lucchese, PO. 1960. Cephalometric appraisal of Class II and Class III malocclusions. Angle Orthod 30:26-32.

Ricketts, Rm. 1952. A study of change in tempromandibular relations associated with the treatment of Class II malocclusion. Am J Orthod 38:918-933.

Ricketts, RM. 1972. The value of cephalometrics and computerized technology. Angle Orthod 42(3):179-199.

Ricketts, RM. 1981. Fifty years of cephalometric radiography. Angle Orthod 51(2):89-91.

Ricketts, RM. 1981. Perspectives in the clinical application of cephalometrics: The first fifty years. Angle Orthod 51(2):115-150.

Rohlf, FJ, and Bookstein, FL. 1988. Proceedings of the Michigan Morphometrics Workshop. The University of Michigan Museum of Zoology. Ann Arbor, University of Michigan Press. 227-228.

Rothstein, T, and Yoon-Tarlie, C. 2000. Dental and facial skeletal characteristics and growth of males and females with class II, division 1 malocclusion between the ages of 10 and 14 (revisited)- part 1; characteristics of size, form, and position. Am J Orthod Dentofacial Orthop 117:320-32.

Salzmann, JA. 1974. Growth of the face. In Orthodontics in daily practice. Philadelphia. J.B. Lippincott Company. Chap. 2.

Savara, BS. 1965. A method for measuring facial growth in three dimensions. Hum Biol 37:245-255.

Scammon, RE, Harris, JA, Jackson, CM, and Patterson, DG. 1930. The measurement of man. Minneapolis, MN. University of Minnesota Press.

Schmid, W, Mongini, F, and Felisio, A. 1991. A computer based assessment of structural and displacement asymmetries of the mandible. Am J Orthod Dentofacial Orthop 100(1):19-34.

Sekiguchi, T, and Savara, BS. 1972. Variability of cephalometric landmarks used for face growth studies. Am J Orthod Dentofacial Orthop 61(6):603-618.

Solow, B. 1970. Computers in cephalometric research. Comp Biol Med 1(1):41-49.

Subramanyan, K, and Dean, D. 1996. Scanned bi-orthogonal radiographs as a source for 3-D cephalometric data. SPIE 2710:717-724.

Thompson, GW, and Popovich, F. 1973 Relationship of craniofacial changes and skeletal age increments in females. Hum Biol 45:595-603.

Todd, W. 1931. The orthodontic value of research and observations in developmental growth of the face. Angle Orthod 1:67.

Tyndall, DA, and Matteson, SR. 1988. Exposure reduction in cephalometric radiology: A comprehensive approach. Am J Orthod Dentofacial Orthop 93(5):400-412.

Vig, PS. 1982. An orthodontist's view of some recent mathematical studies in cephalometrics. Am J Orthod Dentofacial Orthop 81(4):341-342.

Wenger, RT. 1998. Evaluation of Protraction Facemask Therapy Using Traditional Morphometrics and Procrustes Analysis. Master of Science in Dentistry. Cleveland, OH. Case Western Reserve University.

11 122 CW 4932
03/01 TH
00-104-07 GBC